NAS8-37136

March 1989

Appendix I
Honeywell
Avionics Trades
Report

Liquid Rocket Booster (LRB) for the Space Transportation System (STS) Systems Study

(NASA-CR-183795-App-I) LIQUID ROCKET BOOSTER (LRB) FOR THE SPACE TRANSPORTATION SYSTEM (STS) SYSTEMS STUDY. APPENDIX I: HONEYWELL AVIONICS TRADES REPORT (Martin Marietta Corp.) 153 p

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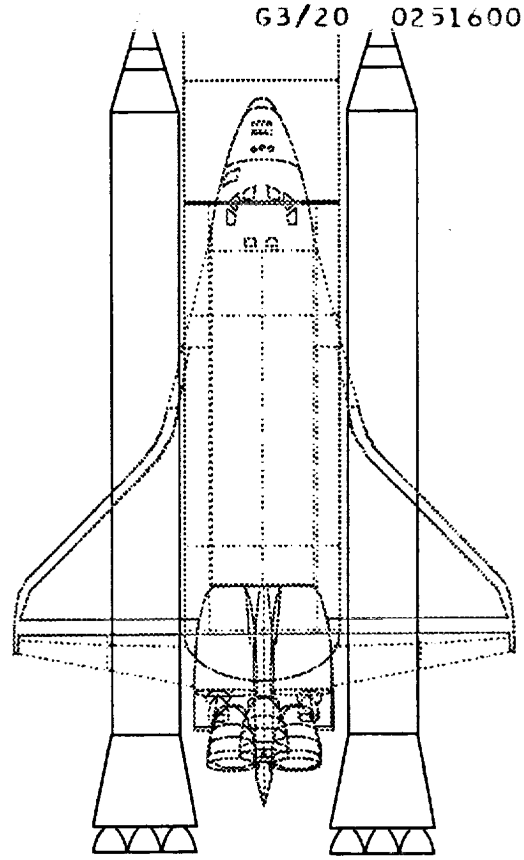

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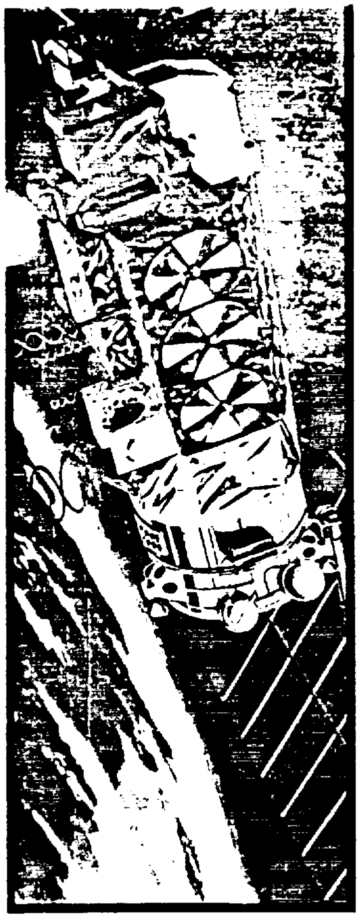
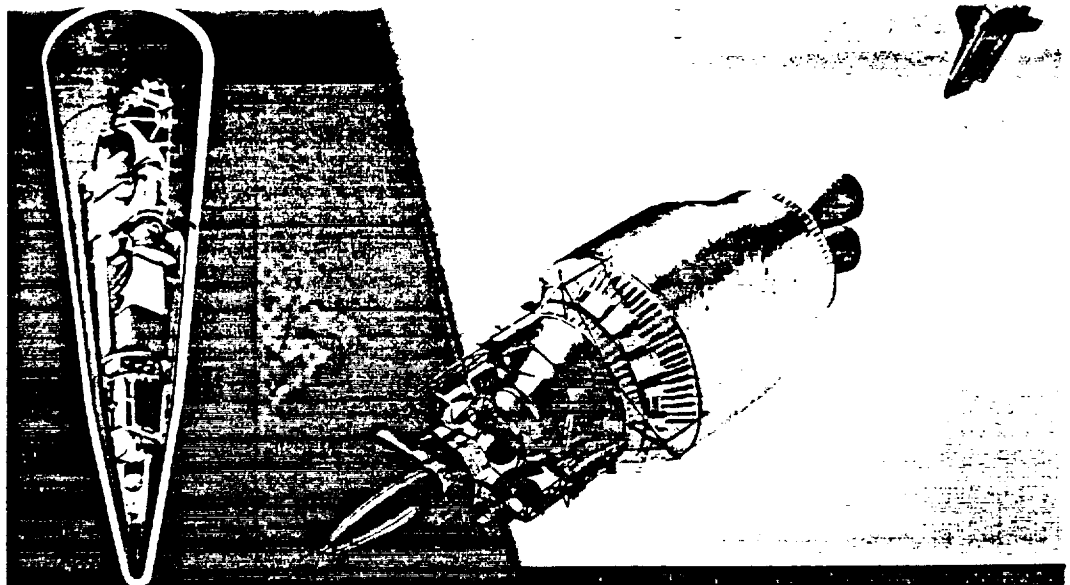
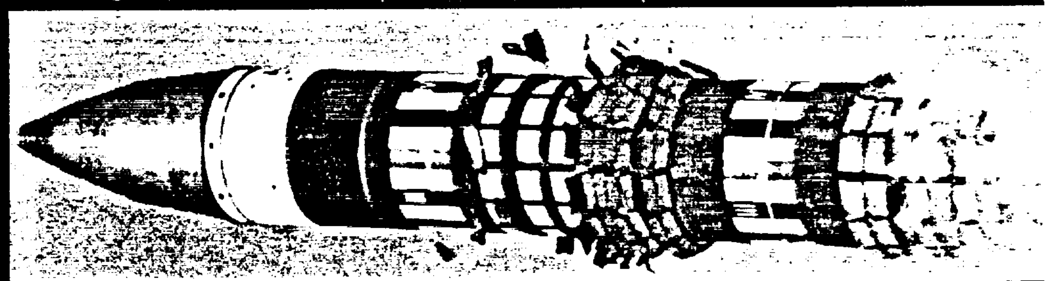
MARTIN MARIETTA
MANNED SPACE SYSTEMS

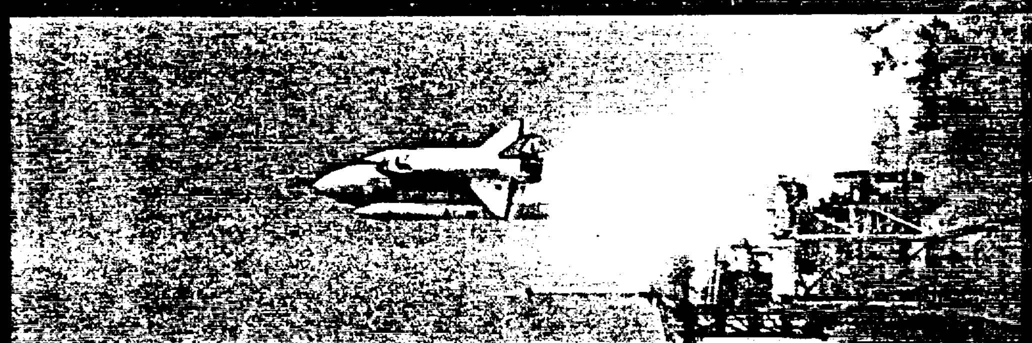
Honeywell Avionics Trades Report

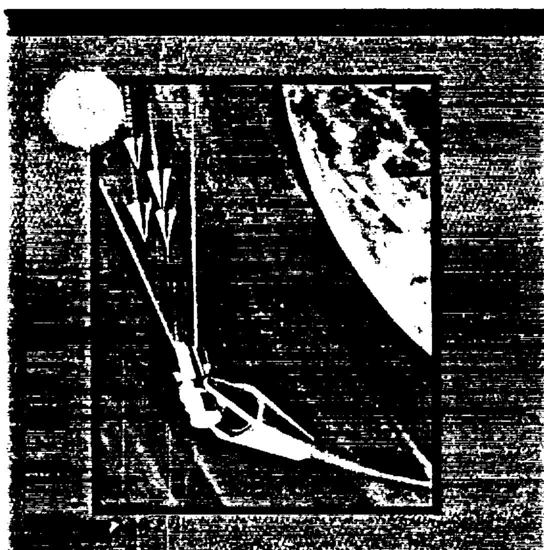
Appendix I











SPACE SYSTEMS OPERATIONS

Honeywell

LRB AVIONICS

TRADE STUDIES

Avionics Architecture Trade Study

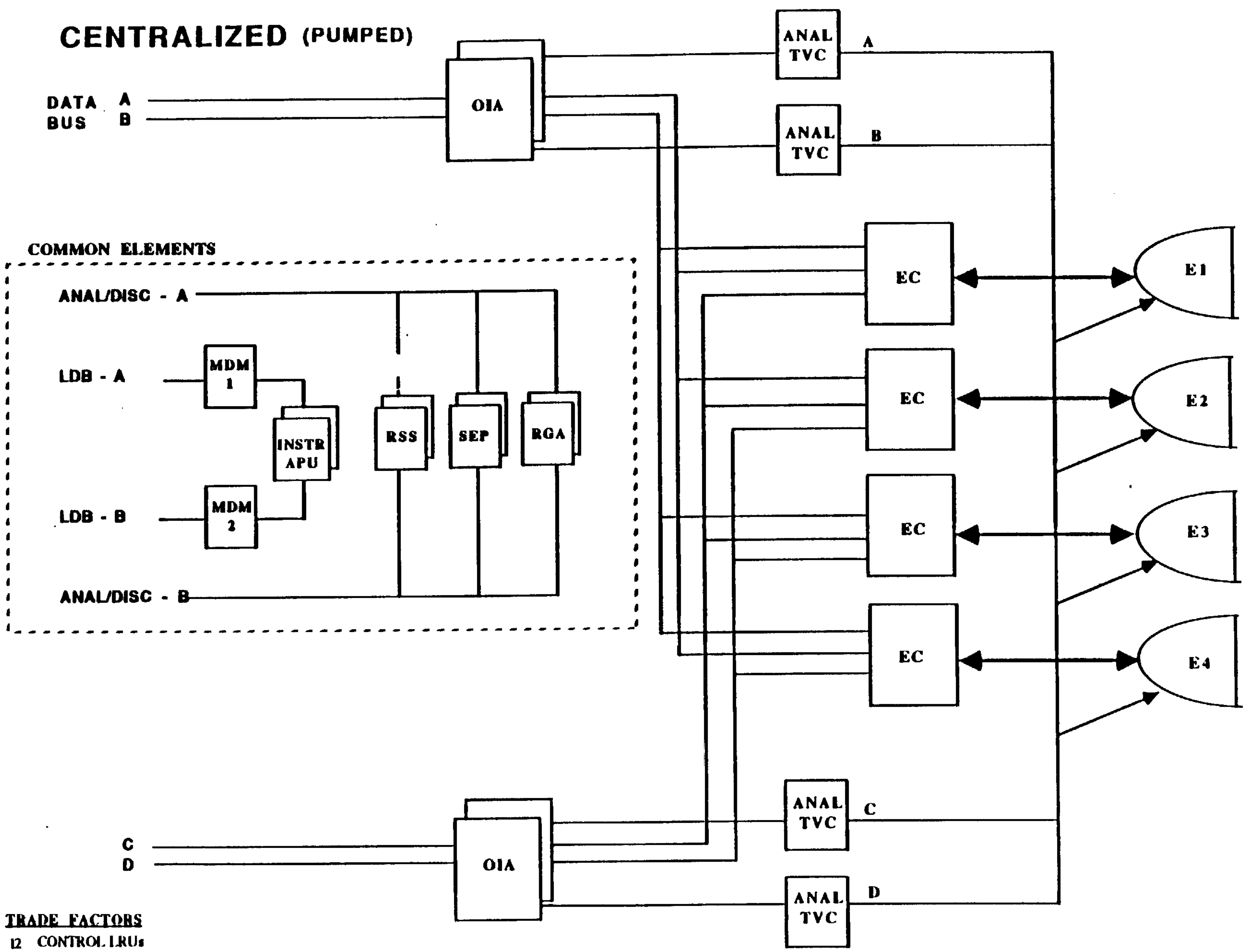
BASELINE: Centralized Control on Pumped LRB
- Separate TVC and EC LRUs
- Analog TVC similar to SSME
- Orbiter Interface Assembly

CANDIDATE 1: Centralized Control on Pressured LRB
- EC and TVC functions in one LRU
- Orbiter Interface Assembly

CANDIDATE 2: Distributed Control on Pumped LRB
- Separate TVC and EC LRUs
- Digital TVC LRU interface

CANDIDATE 3: Distributed Control on Pressured LRB
- EC and TVC in one LRU

CENTRALIZED (PUMPED)

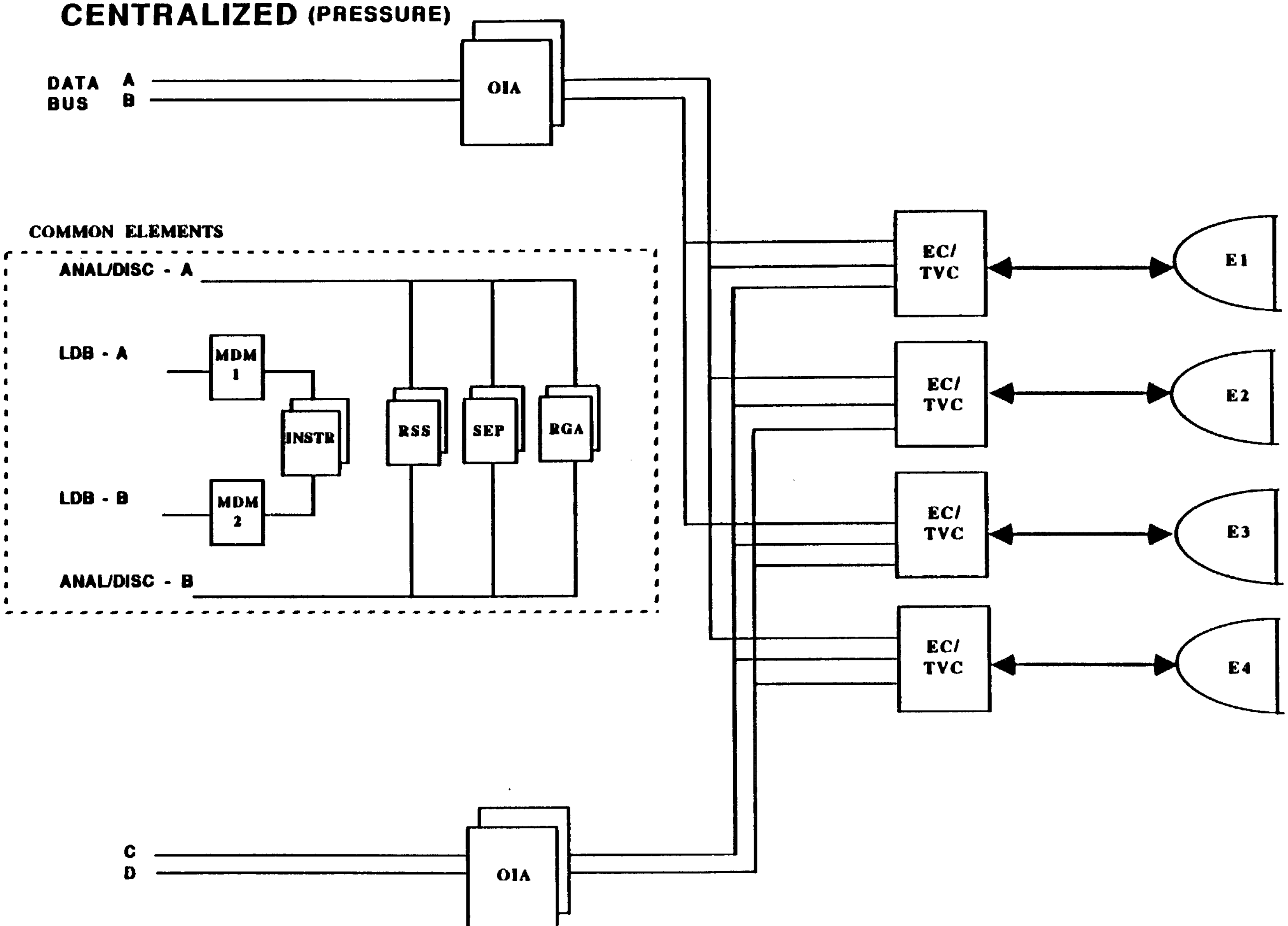


TRADE FACTORS

12 CONTROL LRUs
4 ORBITER INTERFACES
8 SOFTWARE LRUs
680 WEIGHT (LB)

BJM103D

CENTRALIZED (PRESSURE)



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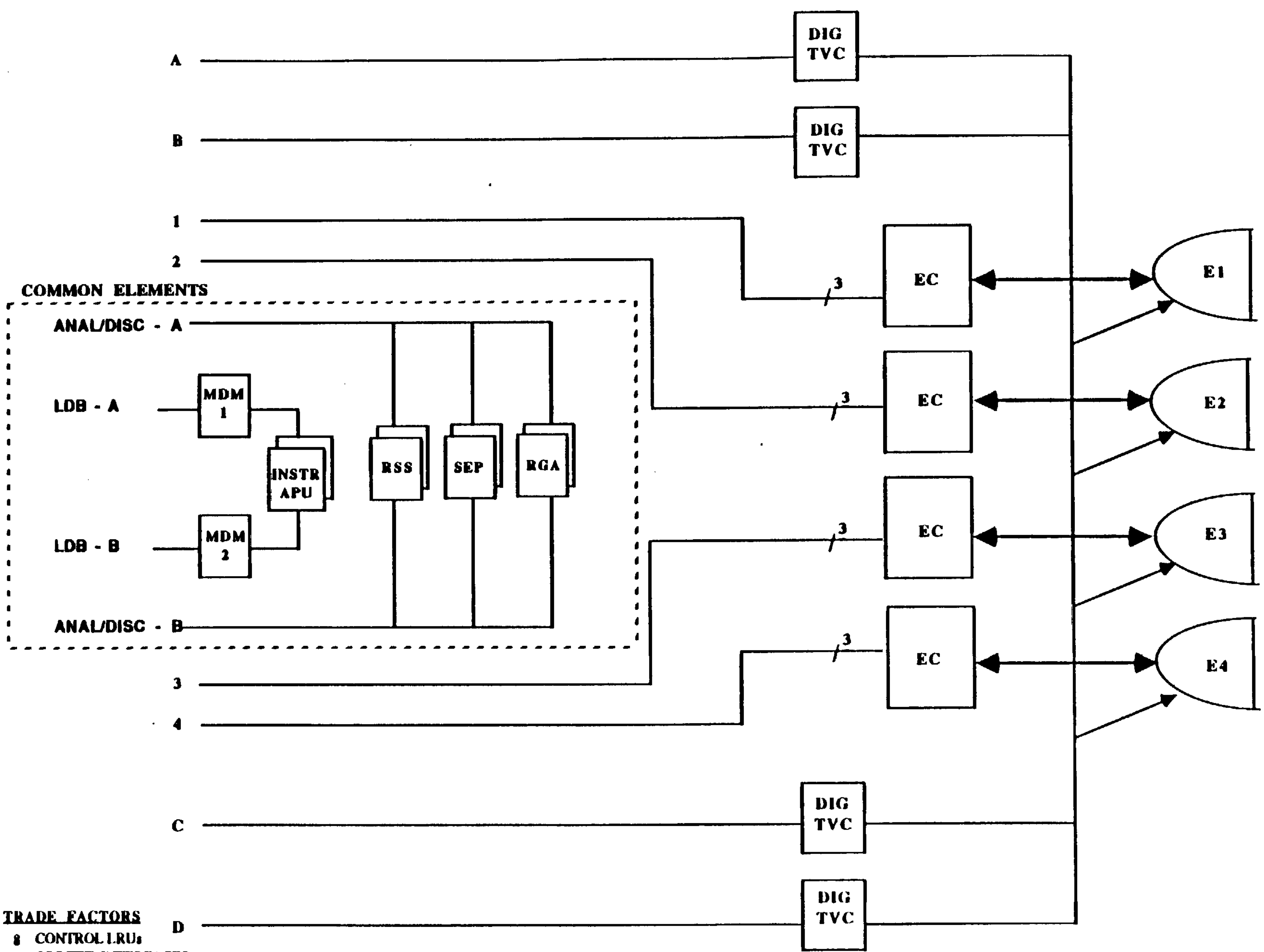
TRADE FACTORS

8 CONTROL LRUs
4 ORBITER INTERFACES
8 SOFTWARE LRUs
520 WEIGHT (LB)

DISTRIBUTED (PUMPED)

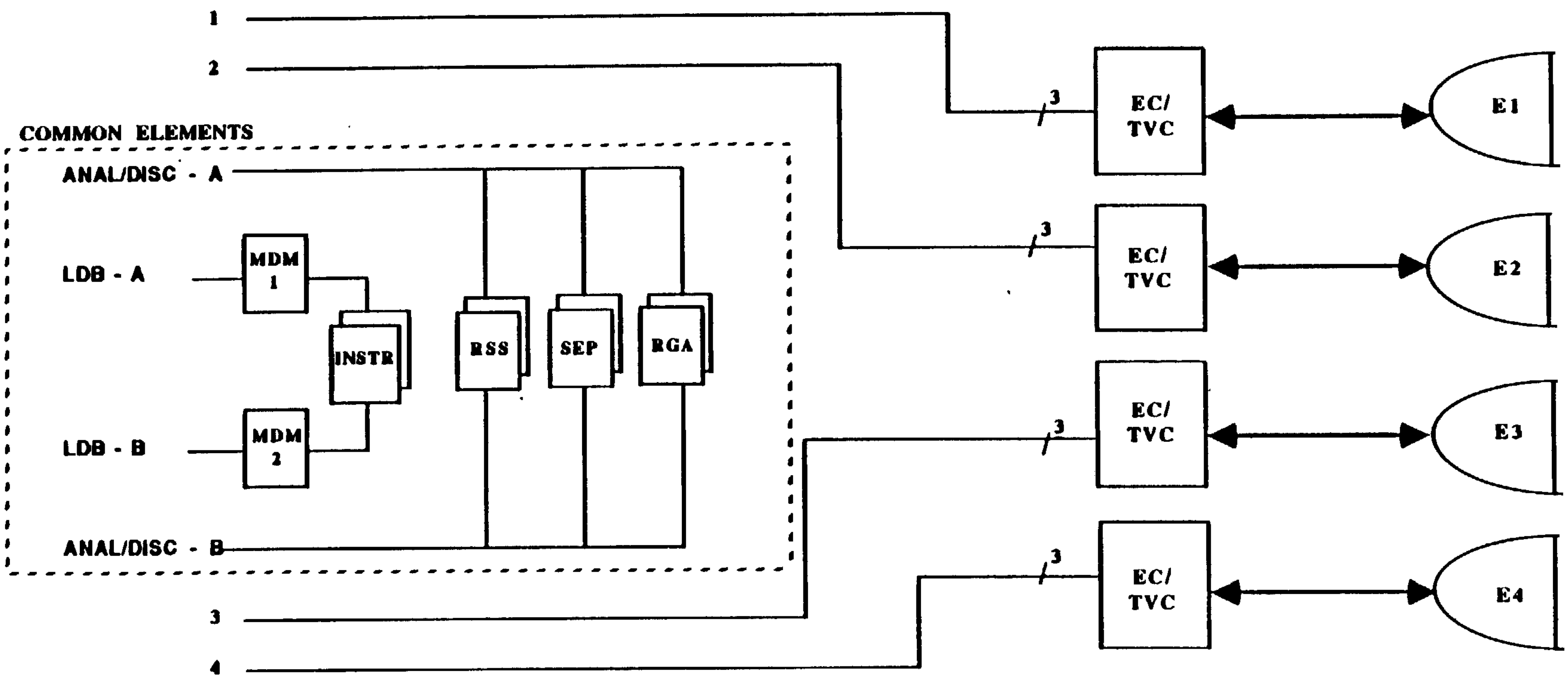


TRADE FACTORS

8 CONTROL LRUs
16 ORBITER INTERFACES
8 SOFTWARE LRUs
560 WEIGHT (LB)

BJM103D

DISTRIBUTED (PRESSURE)



TRADE FACTORS

4 CONTROL LRUs
12 ORBITER INTERFACES
4 SOFTWARE LRUs
400 WEIGHT (LB)

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ARCHITECTURE CHARACTERISTICS

	CENTRALIZED		DISTRIBUTED	
	Pumped	Pressure	Pumped	Pressure
CONTROL LRUS	12	8	8	4
INTERFACES (ORBITER)	4	4	16	12
WEIGHT	680	520	560	400
POWER	680	520	560	400
SOFTWARE LRUs	8	8	8	4

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LRB CONTROL AVIONICS
TRADE STUDY

ARCHITECTURE		CENTRALIZED		DISTRIBUTED	
Criteria (factors)	W	Pumped	Pressure	Pumped	Pressure
STS Integration Impacts (Interfaces)	15	150	150	30	45
DDT&E Costs (LRU types, count)	10	40	50	50	100
Life Cycle Costs (LRU types interfaces, count)	15	105	120	75	150
Operational Complexity (Quantities, interfaces)	10	80	100	60	100
Recovery/Reusability (LRB LRUs)	10	30	50	50	100
Safety/Reliability (LRU count)	10	30	50	50	100
Growth/Evolution (Interfaces)	10	100	100	30	50
Weight (Weight, Quantities)	10	50	80	70	100
Subsystem Integration (LRU quantities)	10	30	50	50	100
TOTALS		615	750	460	825

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AVIONICS ARCHITECTURE TRADE STUDY RESULTS

- A centralized architecture is best for the pumped LRB.
- A distributed architecture is best for the pressured LRB (although significant impact is placed on the orbiter).
- A pressured LRB is preferred for avionics architecture (this may reflect lack of familiarity with pressured requirements).

The assumption that the FC and TVC functions could be combined in one LRU for the pressured LRB significantly affected the results.

EXPENDABLE/REUSABLE AVIONICS TRADE STUDY

BASELINE: EXPENDABLE AVIONICS

CANDIDATE 1: EXPENDABLE AVIONICS

- MAN RATED
  (CLASS "S" REDUNDANT)

CANDIDATE 2: REUSABLE AVIONICS

- MAN RATED
  (IMPROVED STRUCTURE AND SEALS)

EXPENDABLE/REUSABLE AVIONICS TRADE STUDY

CHARACTERISTICS

	EXPENDABLE	REUSABLE
ENVIRONMENT SEAL	.9	1
STRUCTURE	.9	1
CLASS "S" PARTS	1	1
REDUNDANCY	1	1
TESTING	.9	1
PERFORMANCE	1	1
PRODUCTION	1	.1

EXPENDABLE/REUSABLE AVIONICS TRADE STUDY

SCORES

Criteria	Weighting Factor	Expendable Avionics		Reusable Avionics	
		Score	Weighted Score	Score	Weighted Score
STS Integration Impacts	10	10	100	10	100
Life Cycle Costs	20	7	140	10	200
Performance	10	10	100	10	10
Launch Facilities/ Ground Impacts	10	10	100	9	90
Operational Complexitry	5	10	50	10	50
Weight	10	10	100	9	90
Maintainability	5	10	50	10	50
Technical Risks	10	10	100	9	90
Test Requirements	10	10	100	9	90
Growth/Evolution	5	10	50	10	50
Future Applications	5	10	50	10	50
TOTALS	100	107	940	106	960

EXPENDABLE/REUSABLE AVIONICS

RESULTS

- WITH MAN-RATED AVIONICS IN BOTH CANDIDATES, REUSABLE AVIONICS IS A SLIGHTLY PREFERRED SOLUTION.

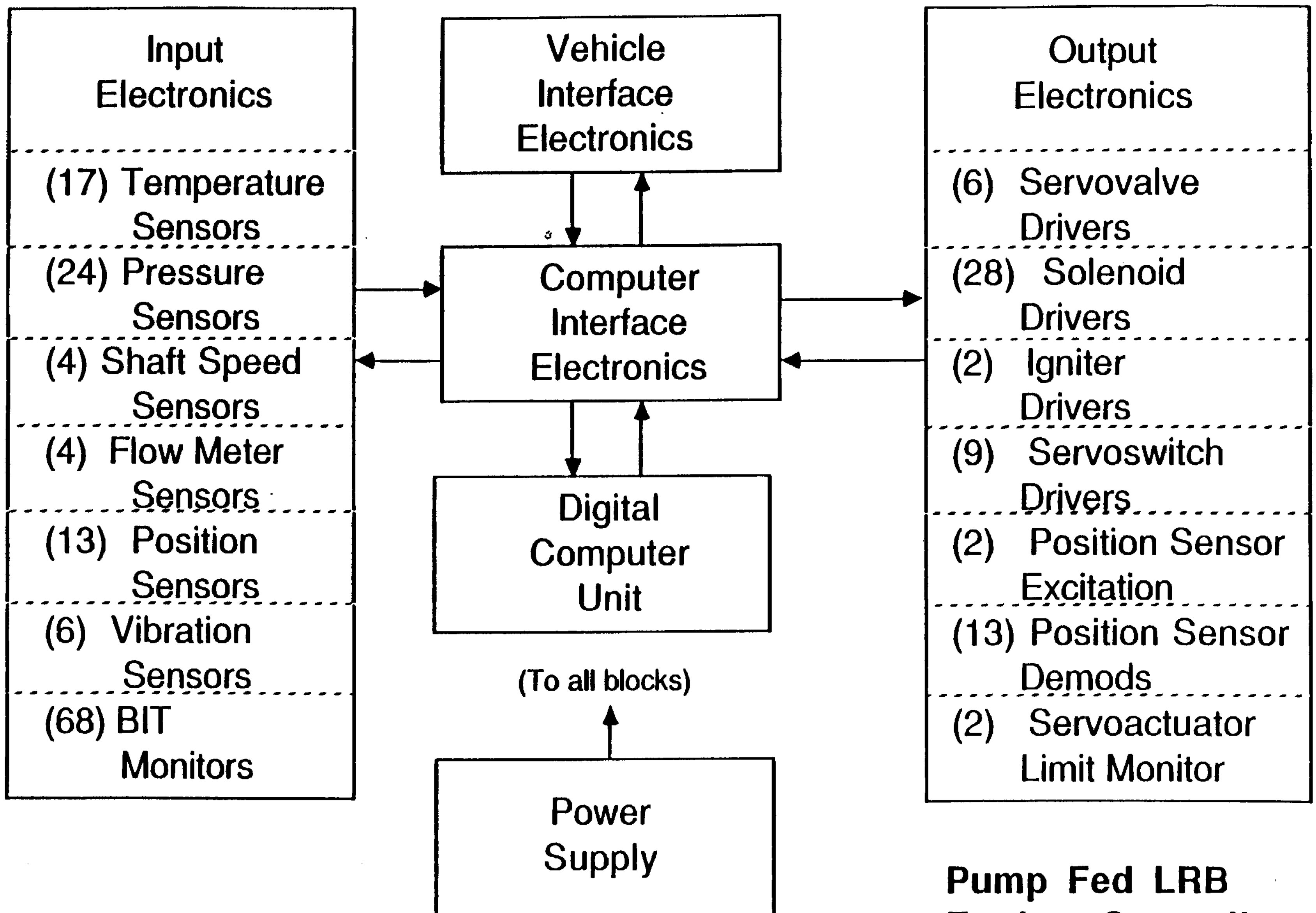
- IF A CLASS "B" REDUNDANT APPROACH WAS PERMISSIBLE (DUE TO THE SHORT FLIGHT TIME), THE EXPENDABLE AVIONICS WOULD BE A CLEAR CHOICE DUE TO COST REDUCTION.

ENGINE CONTROL ELECTRONICS TRADE STUDY

BASELINE: PUMP-FED ENGINE CONTROLLER

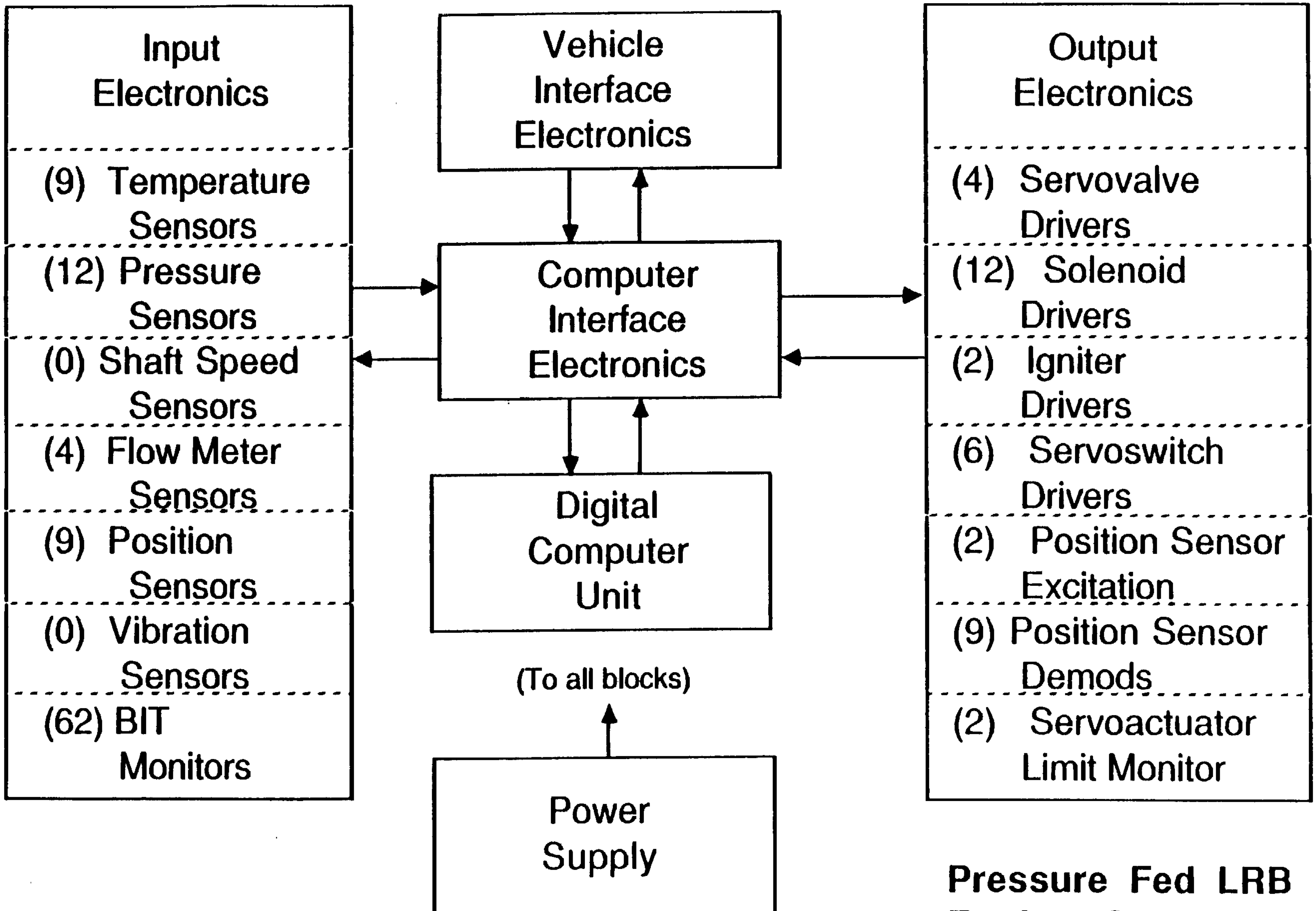
CANDIDATE 1: PUMP-FED CONTROLLER
- BASED ON SSMEC CONTROLLER (MAN-RATED, DUAL REDUNDANT)

CANDIDATE 2: PRESSURE-FED CONTROLLER
- BASED ON SSMEC CONTROLLER



Pump Fed LRB Engine Controller

BJM001a/SS



Pressure Fed LRB Engine Controller

ENGINE CONTROL ELECTRONICS TRADE STUDY

CHARACTERISTICS

	PUMPED EC	PRESSURED EC
INPUTS	136	96
OUTPUTS	62	37
CARD COUNT	43	38
SIZE	180	155
POWER	350	328

ENGINE CONTROL ELECTRONICS

TRADE STUDY

SCORES

CRITERIA	Weighting Factor	Pump-Fed Engine		Pressure-Fed Engine	
		Score	Weighted Score	Score	Weighted Score
DDT &E Costs	10	9	90	10	100
Life Cycle Costs	20	8	160	10	200
Operational Complexity	10	7	70	10	100
Recovery/Reusability	10	10	100	10	100
Size	10	9	90	10	100
Power	10	9	90	10	100
Safety	20	9	180	10	200
Technical Risks	10	10	100	10	100
TOTAL	100	71	880	80	1000

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ENGINE CONTROL ELECTRONICS

TRADE STUDY

RESULTS

- THE PRESSURE-FED ENGINE'S REDUCED CONTROL REQUIREMENTS CAN BE SATISFIED BY A MORE MODEST CONTROLLER.

THRUST VECTOR CONTROL
AVIONICS TRADE STUDY

BASELINE: HYDRAULIC ACTUATOR TVC FOR PUMPED LRB

FLUID INJECTION TVC FOR PRESSURIZED LRB

CANDIDATE 1: FLUID INJECTION AVIONICS

- Drives 24 injection port valves on each engine
- Electric motor driven valves
- Dual electronic drivers

CANDIDATE 2: HYDRAULIC ACTUATOR AVIONICS

- Same as STS actuator drive electronics
- TILT and ROCK channels
- Quad redundancy

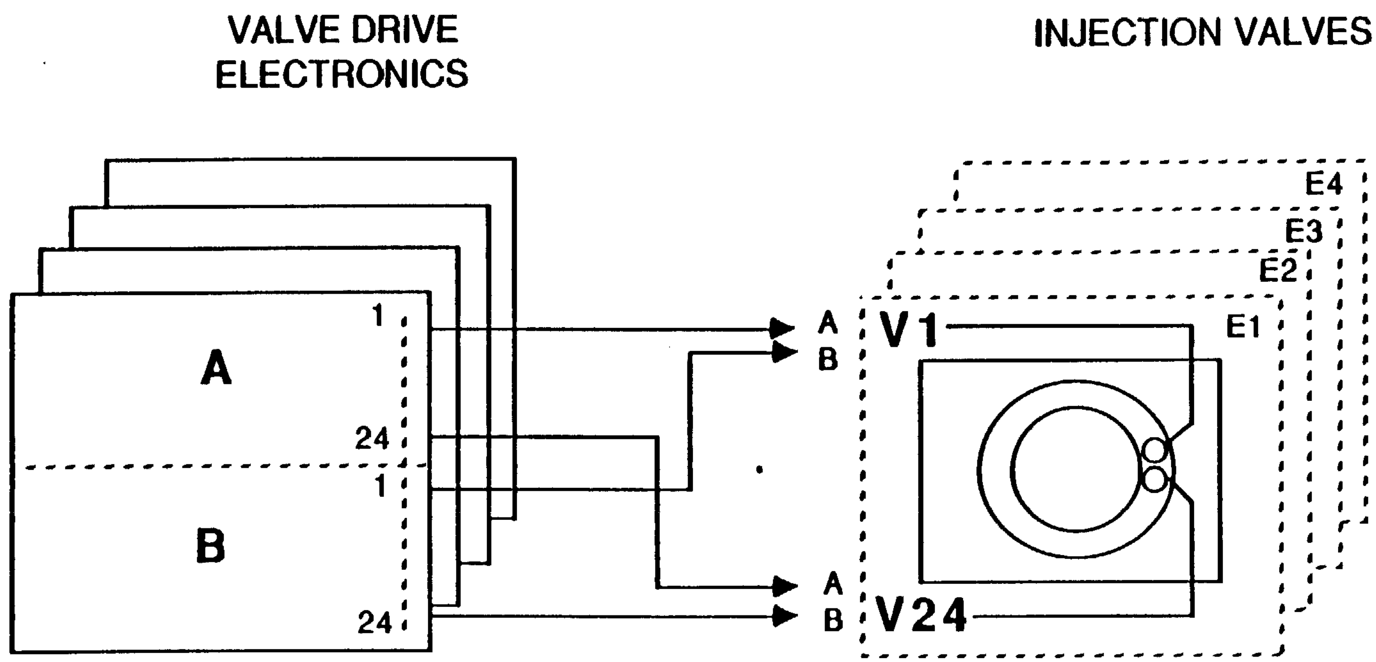
CANDIDATE 3: ELECTROMAGNETIC ACTUATOR AVIONICS

- Four motors per actuator
- TILT and ROCK channels
- Quad redundancy

BJM002/SS

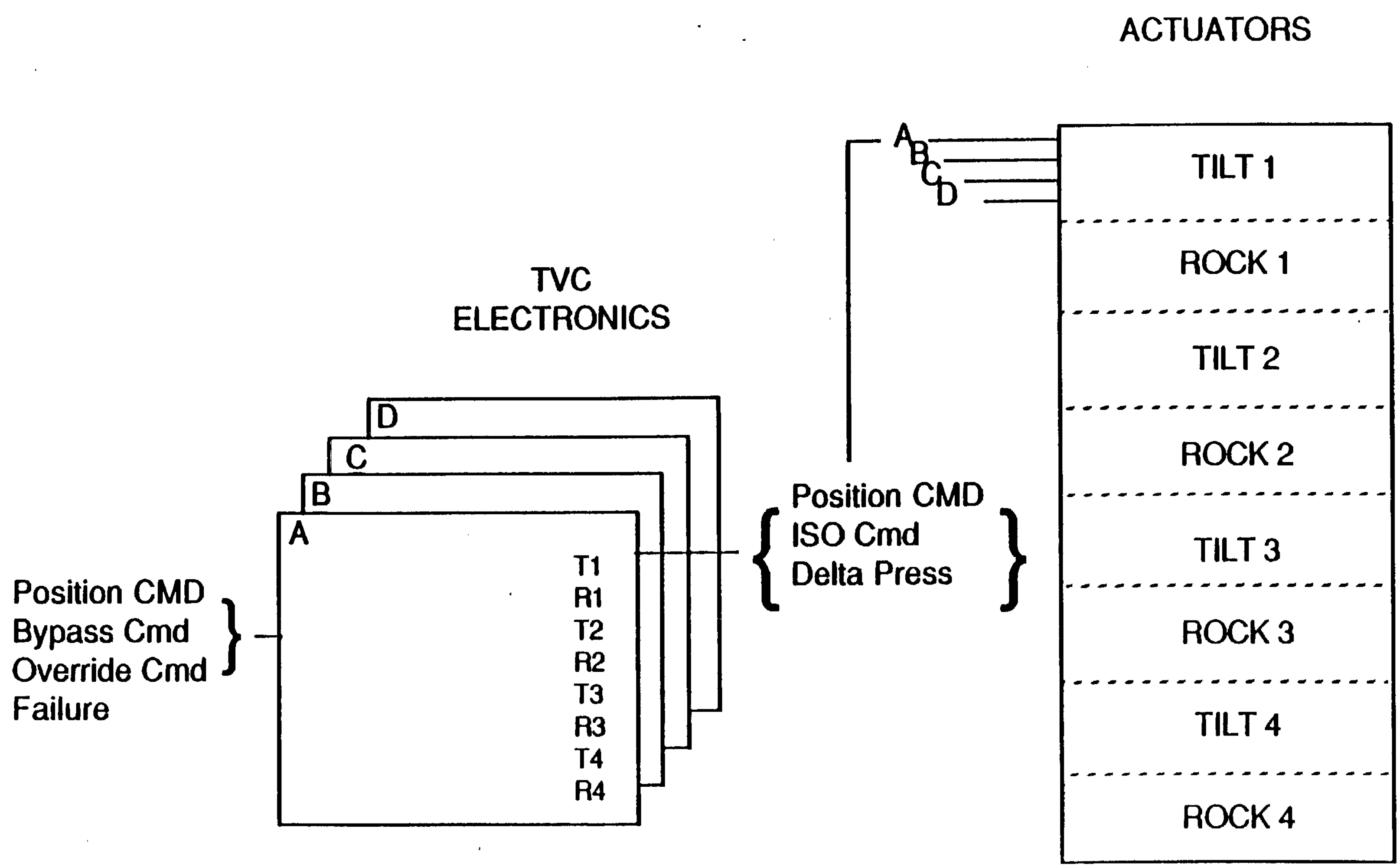
Fluid Injection

BJM001/SS



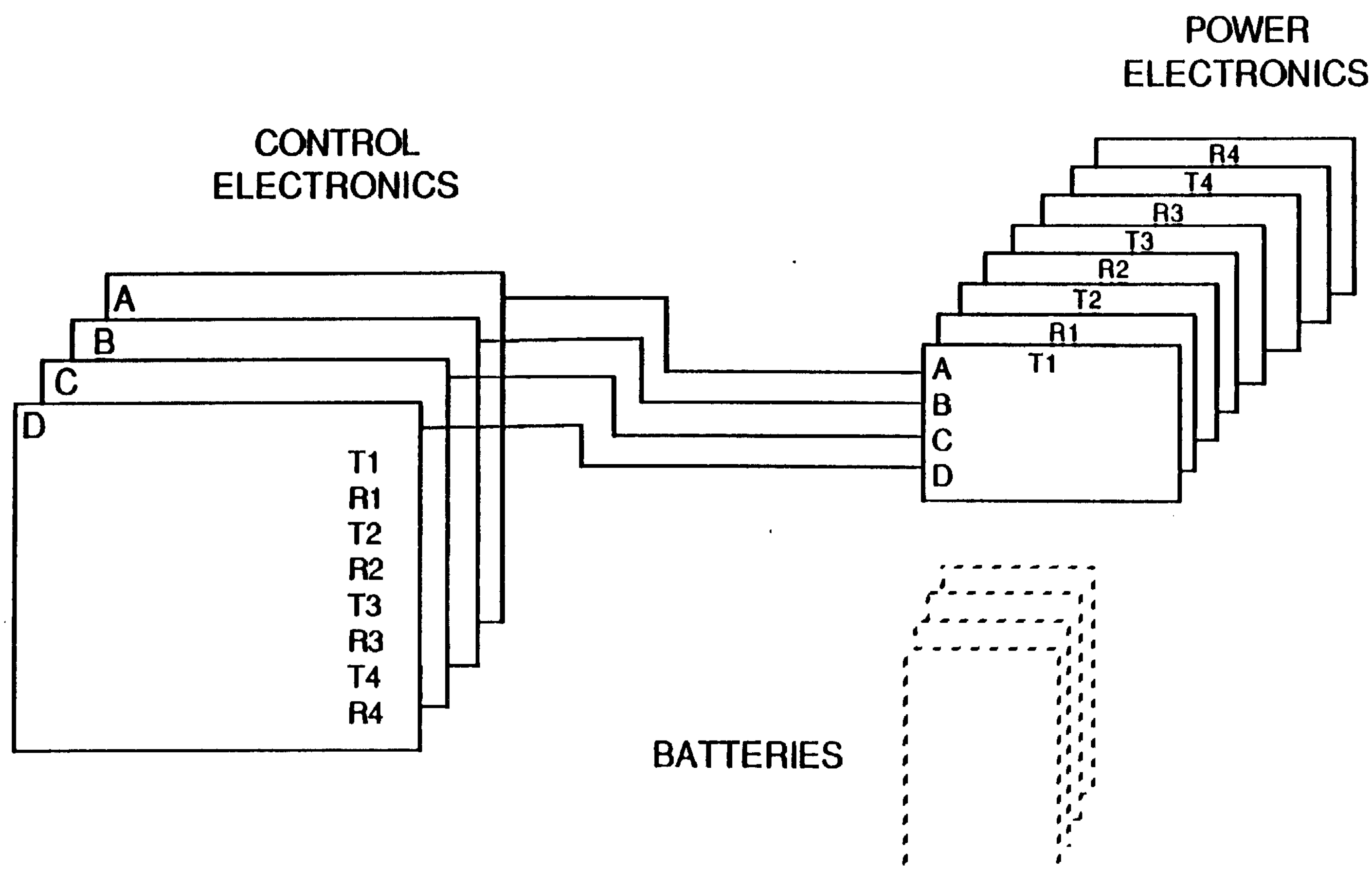
Hydraulic Actuators

BJM001c/SS



Electromagnetic Actuators

BJM001/SS



THRUST VECTOR CHARACTERISTICS

	FLUID INJECTION	HYDRAULIC ACTUATORS	ELECTROMAGNETIC ACTUATORS
LRU COUNT	4	4	12
LRU TYPES	1	1	2
DEVELOPMENT	in use	on STS	new
I/F	4x24 (96)	4x8 (32)	2x4x8 (64)
WEIGHT	4x40 (160)	4x40 (160)	4x40+8x20 (320)

BJM002/SS

TVC
AVIONICS TRADE STUDY

SCORES

Criteria	Weighting Factor	Fluid Injection	Hydraulic Actuators	Electromagnetic Actuators
DDT&E Costs	10	80	100	40
Life Cycle Costs	20	180	200	140
Performance	10	40	100	60
Operational Complex.	10	100	50	80
Weight	10	100	100	50
Recovery/Reusability	10	100	100	30
Safety/Reliability	10	100	100	30
Size	10	100	100	30
Technical Risks	10	80	100	50
TOTALS		880	950	510

TVC AVIONICS TRADE STUDY

RESULTS

- HYDRAULIC TVC IS THE BEST SOLUTION IN AN AVIONICS COMPARISON DUE TO MATURITY OF THE TECHNOLOGY.
- FLUID INJECTION TVC IS A CLOSE SECOND WITH THE MAJOR WEAKNESS IN PERFORMANCE UNCERTAINTY.
- ELECTROMAGNETIC ACTUATOR TVC WILL REQUIRE SIGNIFICANT DEVELOPMENT COSTS AND THE ELECTRONIC COMPLEXITY COMPARES UNFAVORABLY ON AN AVIONICS ONLY BASIS.

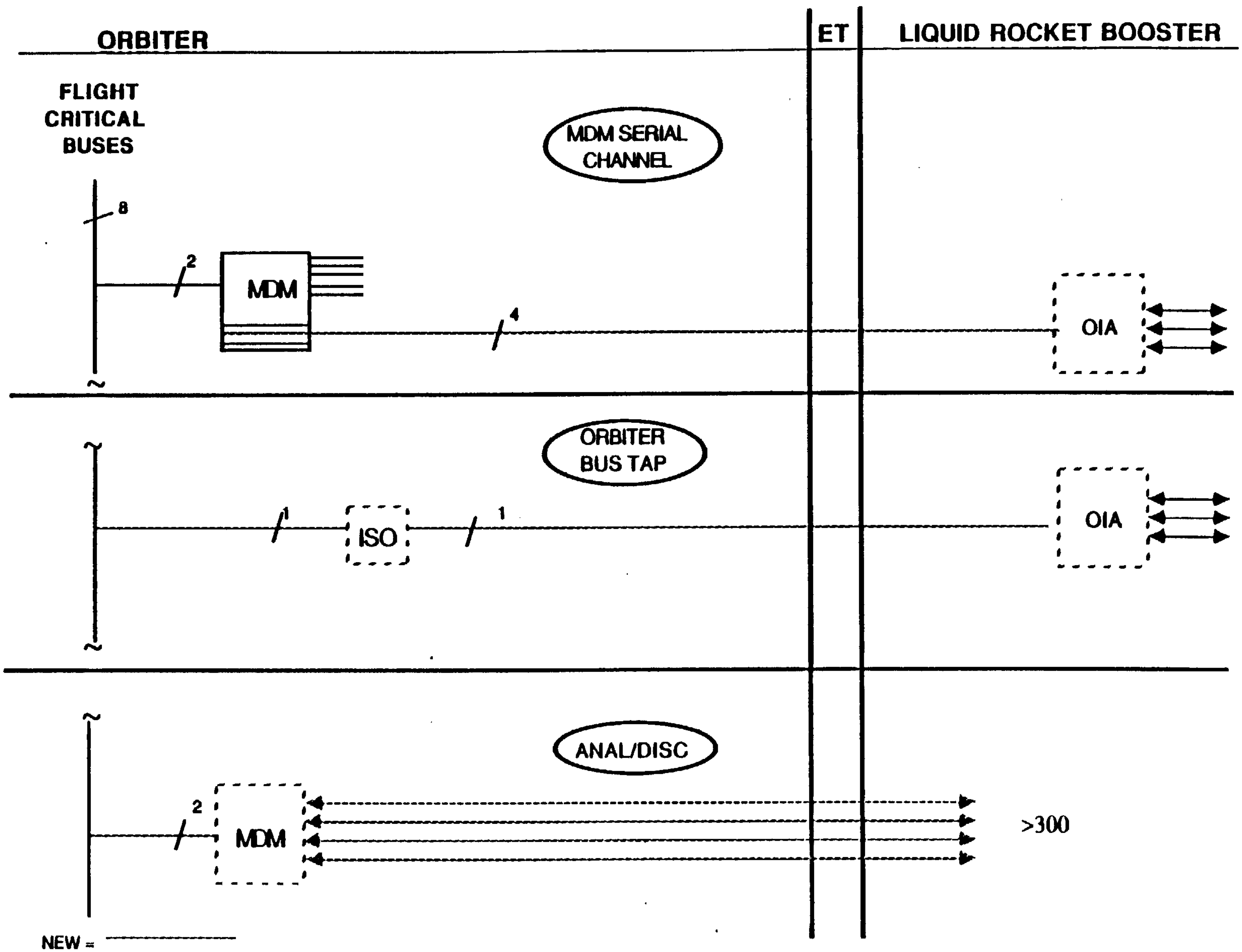
Avionics Interfaces
Trade Study

BASELINE: Retain SRB interfaces for elements common to SRB and LRB avionics configurations. Use wiring freed by dropping hardwared TVC signals for new data bus requirements. (4rqd for quad redundancy.)

CANDIDATE 1: MDM Serial channels added to existing MDMs
- Communications with centralized orbiter interface adapters (OIAs) in LRB
- Time delay to transfer from FC bus to MDM bus

CANDIDATE 2: New Flight Critical bus taps added
- Direct interfaces to OIAs in LRB
- Impacts orbiter bus distribution architecture

CANDIDATE 3: New MDMs added for direct signal generation for non-centralized LRB avionics
- Impacts orbiter bus distribution architecture
- Requires additional interface connectors to LRB


ORBITER
ET
LIQUID ROCKET BOOSTER
FLIGHT CRITICAL BUSES
8
2
MDM
4
MDM SERIAL CHANNEL
OIA
ORBITER BUS TAP
1
ISO
1
OIA
ANAL/DISC
2
MDM
>300
NEW =

BJM104D

INTERFACE CHARACTERISTICS

	MDM SERIAL	ORB BUS TAPS	ANALOG/ DISCRETE
I/F WIRES	16 TSP (4CH)	4 TSP (4CH)	300 +
TRANSPORT DELAY	ADDED DELAY	STANDARD	STANDARD
ORBITER HW MODS	4 SERIAL MDM CARDS	4 ISO XFMRS	MDMS, CONNECTORS, WIRING
SOFTWARE	ADDED GPC FUNCTIONS	BUS ARCH IMPACT + ADD'L FUNCTIONS	BUS ARCH + ADDED GPC FUNCTIONS

BJM104D

AVIONICS IN?ERFACES TRADE STUDY SCORES

Criteria (FACTOR)	W	MDMs	Orbiter Bus	Analog/Discrete
STS Integration Impacts (W,D,H,S)	20	160	200	100
DDT&E Costs (H,S)	10	100	90	70
Life Cycle Costs (H,S,W)	20	160	200	120
Operational Complexity (W,H)	10	80	100	20
Technical Risks (D,S,W)	10	100	100	60
Safety/Reliability (H)	10	80	100	20
Subsystem Integration (W)	10	80	100	10
Growth/Evolution (W)	10	80	100	50
TOTALS		840	990	450

W = Wiring
D = Delay
H = Hardware
S = Software

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AVIONICS INTERFACES TRADE STUDY RESULTS

- The orbiter bus tap is the best solution for the LRB avionics interface followed closely by MDM serial bus.

- An Analog/discrete interface would require added ORB/ET/LRB cabling.

SOFTWARE LANGUAGE TRADE STUDY

BASELINE:	Orbiter - HAL-S LRB - ADA
CANDIDATE 1:	HAL-S
CANDIDATE 2:	ADA
CANDIDATE 3:	Assembly Language
CANDIDATE 4:	C

SOFTWARE LANGUAGE CANDIDATES

HAL-S

STRENGTHS

1. MATURE AND PROVEN SOFTWARE LANGUAGE
2. EXISTING DEVELOPMENT AND SUPPORT ENVIRONMENT
3. STRUCTURED LANGUAGE

WEAKNESSES

1. DATED SOFTWARE LANGUAGE WITH LITTLE CONTINUING DEVELOPMENT.
2. NO COMMONALITY WITH SPACE STATION.
3. DESIGNED FOR GENERAL PURPOSE COMPUTERS, NOT REAL TIME CONTROLLERS.
4. NO CURRENT TECHNOLOGY SOFTWARE DEVELOPMENT TOOLS.
5. NOT A DOD OR NASA SPONSORED LANGUAGE.
6. NO OUTSIDE VENDOR COMMITMENTS.
7. NO QUANTITY OF TRAINED SOFTWARE ENGINEERS.

SOFTWARE LANGUAGE CANDIDATES

ADA

STRENGTHS

1. HIGHLY STRUCTURED LANGUAGE
2. COMPLETE SOFTWARE DEVELOPMENT TOOL SET.
3. DOD AND NASA SPONSORSHIP.
4. HUGE SUBCONTRACTOR INVESTMENT
5. COMPETITIVE VENDOR ENVIRONMENT.
6. EMPHASIS NOW ON EFFICIENCY AND REAL TIME
7. PROVIDES COMMONALITY WITH SPACE STATION
8. LARGE TRAINING ACTIVITY BY SPACE STATION AND DOD SUBCONTRACTORS
9. EXTENSIVE DOCUMENTATION TOOLS AND STANDARDS
10. LARGE BASE OF SOFTWARE PACKAGES AND LIBRARIES

WEAKNESSES

1. CURRENTLY WEAK IN EFFICIENCY AND REAL TIME
2. CURRENTLY NOT MATURE

SOFTWARE LANGUAGE CANDIDATES

ASSEMBLY LANGUAGE

STRENGTHS

1. SUPPORTS REAL TIME APPLICATIONS
2. EFFICIENT CODE GENERATION

WEAKNESSES

1. NOT A STRUCTURED LANGUAGE
2. NO COMMONALITY WITH SPACE STATION
3. FEW DOCUMENTATION AND SOFTWARE MANAGEMENT TOOLS
4. NO NASA OR DOD SPONSORSHIP
5. DIFFICULT TO VALIDATE
6. DIFFICULT TO MODIFY, MAINTAIN AND APPLY GROWTH.

SOFTWARE LANGUAGE CANDIDATES

• C

STRENGTHS

1. HIGHLY STRUCTURED LANGUAGE
2. COMPLETE SOFTWARE DEVELOPMENT TOOL SET.
3. LARGE COMMERCIAL APPLICATION BASE.
4. REAL TIME CAPABILITY.
5. EFFICIENT CODE GENERATION.
6. EXTENSIVE DOCUMENTATION TOOLS.
7. LARGE BASE OF SOFTWARE LIBRARIES.
8. MATURE AND PROVEN SOFTWARE LANGUAGE.
9. LARGE BASE OF TRAINNED ENGINEERS.
10. LARGE PROCESSOR TARGET BASE.

WEAKNESSES

1. NON DOD OR NASA SPONSORSHIP
2. NOT BASELINED IN SSE FOR SPACE STATION

SOFTWARE LANGUAGE

TRADE STUDY

SCORES

CRITERIA	Weighting Factor	HAL-S		ADA		Assy Language		C	
		Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
STS Integration Impacts	20	5.5	110	9.4	188	5.0	100	10	200
DDT &E Costs	20	4.3	86	10	200	4.1	82	9.0	180
Technical Risks	20	4.6	92	10	200	5.1	102	9.6	192
Safety/Reliability	20	5.4	108	10	200	6.8	136	9.6	192
Subsystem Integration	10	3.0	30	10	100	6.1	61	9.4	94
Test Requirements	10	4.2	42	10	100	4.5	45	9.2	92
TOTAL	100		460		988		526		950

BJM107D/S

LRB STUDY RESULTS

ADA AND C ARE CLEAR LEADERS

- HIGHLY STRUCTURED
- COMPLETE SET OF DEVELOPMENT TOOLS
- COMPLETE SET OF DOCUMENTATION TOOLS
- LARGE BASE OF USERS (DOD & NASA CONTRACTORS)
- LARGE PROCESSOR TARGET BASE (MICROS, MINIS, MAINFRAMES)

ADA IS PREFERRED

- ENDORSED BY DOD AND NASA
- INVESTMENT BY SUBCONTRACTORS, VENDORS, DOD, NASA
- NATIONAL STANDARD
- RAPID DEVELOPMENT AND CERTIFICATION PROCESS
- EXTENSIVE TRAINING IN PROGRESS

AVIONICS

TRADE STUDY

BACKUP

ARCHITECTURE TRADE STUDY

Centralized and distributed avionics architecture concepts are proposed for the pumped and pressurized LRB vehicles. The centralized versions minimize the control interface to the orbiter by introducing OIA units (for Orbiter Interface Assembly). The OIA interfaces a serial databus from the orbiter to diverse LRB avionics signals. The LRB avionics whose functions are not engine-oriented are handled architecturally the same as in the SRB.

The baseline architecture uses EC (engine controller) and TVC (thrust vector control) units based on the SSME EC and ATVC units. The SSME has a triple redundant serial bus to interface with the orbiter GPC. The ATVC has all analog and discrete interfaces. These signals are funnelled to quad redundant OIA's to maintain the two failure tolerant control requirements.

The pressurized LRB avionics architectures reflect a desire to mechanize the engine control and thrust vector control functions in one unit if permitted by engine control complexity reduction.

STS Integration Impacts

Architecture impact upon STS integration for the avionics is in the areas of the orbiter interface. A centralized architecture minimizes the interface by collecting LRB functions and funnelling them to a minimum number of serial buses. Orbiter hardware revisions are also minimized due to less interface.

	C		D	
	PU	PR	PU	PR
Interfaces	4	4	16	12
Score	(10)	(10)	(2)	(3)

DDT & E Costs

DDT & E cost of a centralized architecture will be more than the distributed architecture due to an increased number of components required to do the centralized control. This cost differential may be cancelled by orbiter costs, however, to handle the additional interfaces of a distributed architecture.

	C		D	
	PU	PR	PU	PR
LRU TYPES	3(3)	2(5)	2(5)	1(10)
SW LRUS	8(5)	8(5)	8(5)	4(10)
	8	10	10	20
	4	5	5	10

Life Cycle Costs

DDT & E + Production + Operations

		C		D	
		PU	PR	PU	PR
DDT & E(other sheet)					
	Score	(4)	(5)	(5)	(10)
Production					
Component	count	12	8	8	4
	sc	(3)	(5)	(5)	(10)
Operations					
I/F count		4	4	12	8
		(10)	(10)	(3)	(5)
	Total sc	17	20	13	25
		7	8	5	10

Operational Complexity

Function of number of LRUs and interfaces

	C		D	
	PU	PR	PU	PR
LRUs	12	8	8	4
I/F	4	4	12	8
	16	12	20	12
	(8)	(10)	(6)	(10)

Recovery/Reusability

Inverse functions of LRU count (amount of refurbishment required).

		C		D	
		PU	PR	PU	PR
LRU	count	12	8	8	4
	score	(3)	(5)	(5)	(10)

Safety/Reliability

Inverse of LRU count

C		D	
PU	PR	PU	PR
12	8	8	4
(3)	(5)	(5)	(10)

Growth/Evolution

Centralized better since interfaces are not overloaded (inverse functions of interface)

	C		D	
	PU	PR	PU	PR
I/F	4	4	12	8
	(10)	(10)	(3)	(5)

Weight

Centralized heavier due to added LRUs:

(~680 vs 560)

C= (30 + 100 + 40) x 4 = 680

D= (100 + 40) x 4 = 560

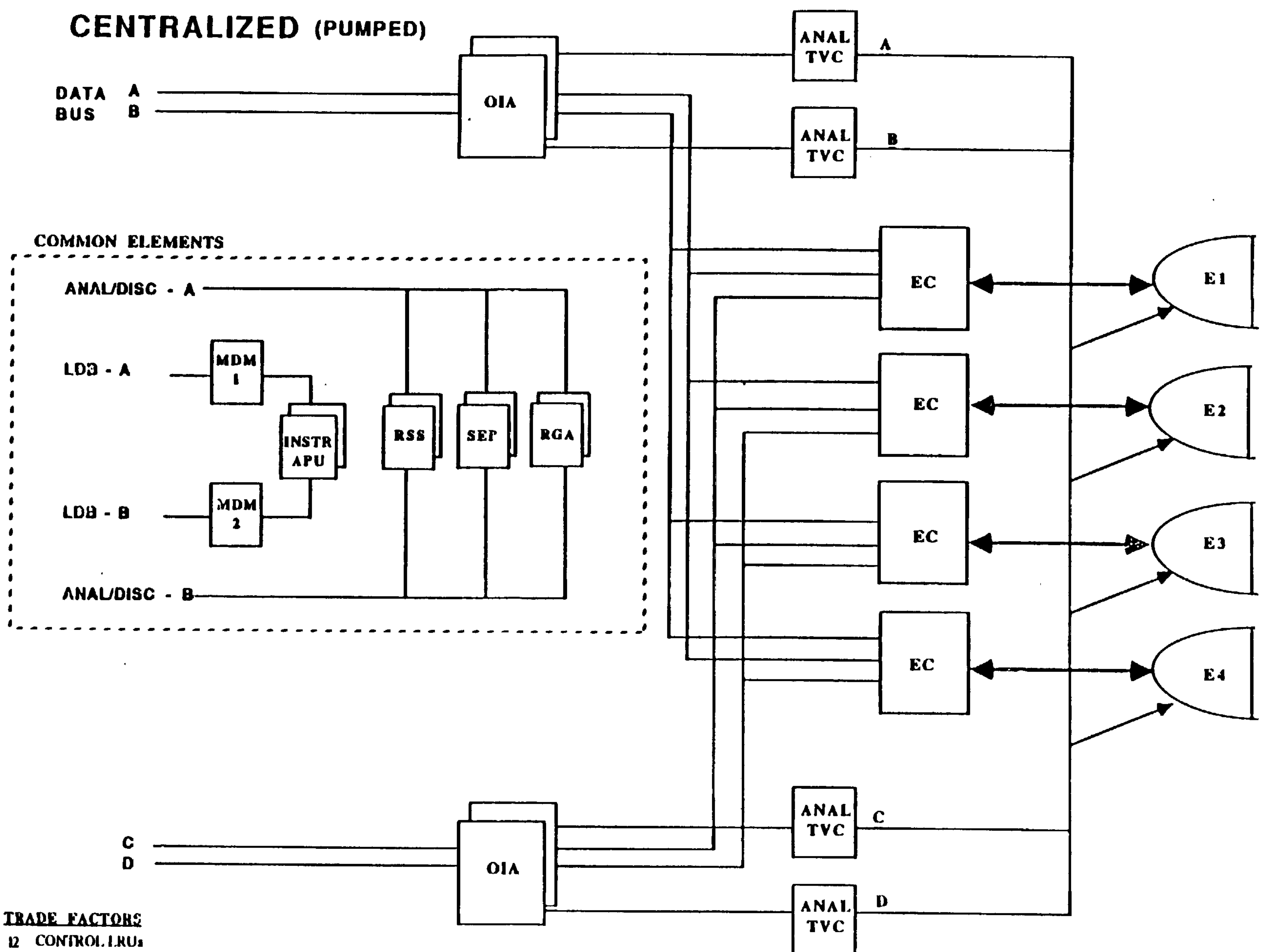
C		D	
PU	PR	PU	PR
680	520	560	400
(5)	(8)	(7)	(10)

Subsystem Integration

Function of the number of LRUs

		C		D	
		PU	PR	PU	PR
LRU	count	12	8	8	4
	score	(3)	(5)	(5)	(10)

CENTRALIZED (PUMPED)

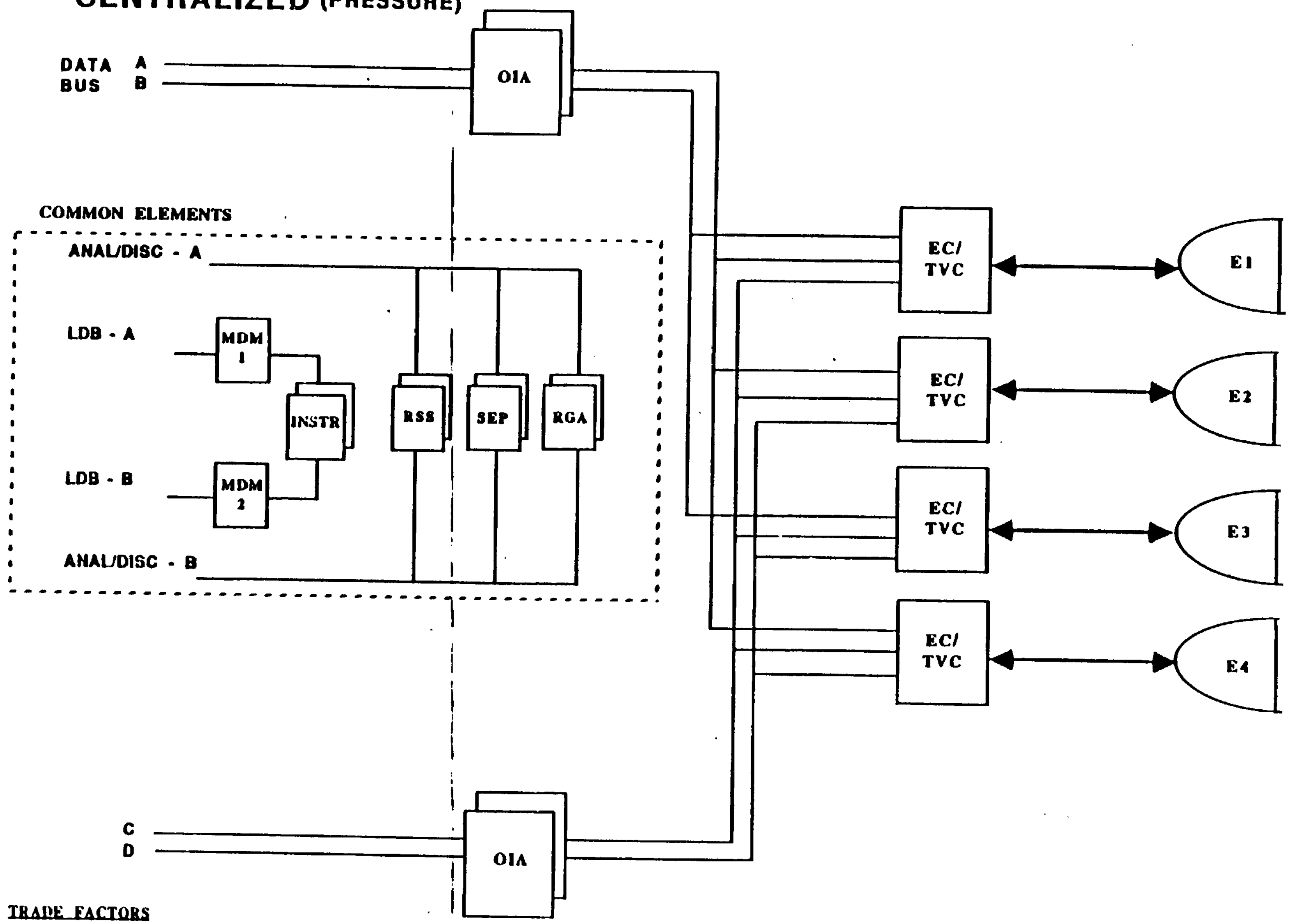


TRADE FACTORS

12 CONTROL LRUs
4 ORBITER INTERFACES
8 SOFTWARE LRUs
680 WEIGHT (LB)

BJM103D

CENTRALIZED (PRESSURE)



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520 WEIGHT (LB)

BJM103D

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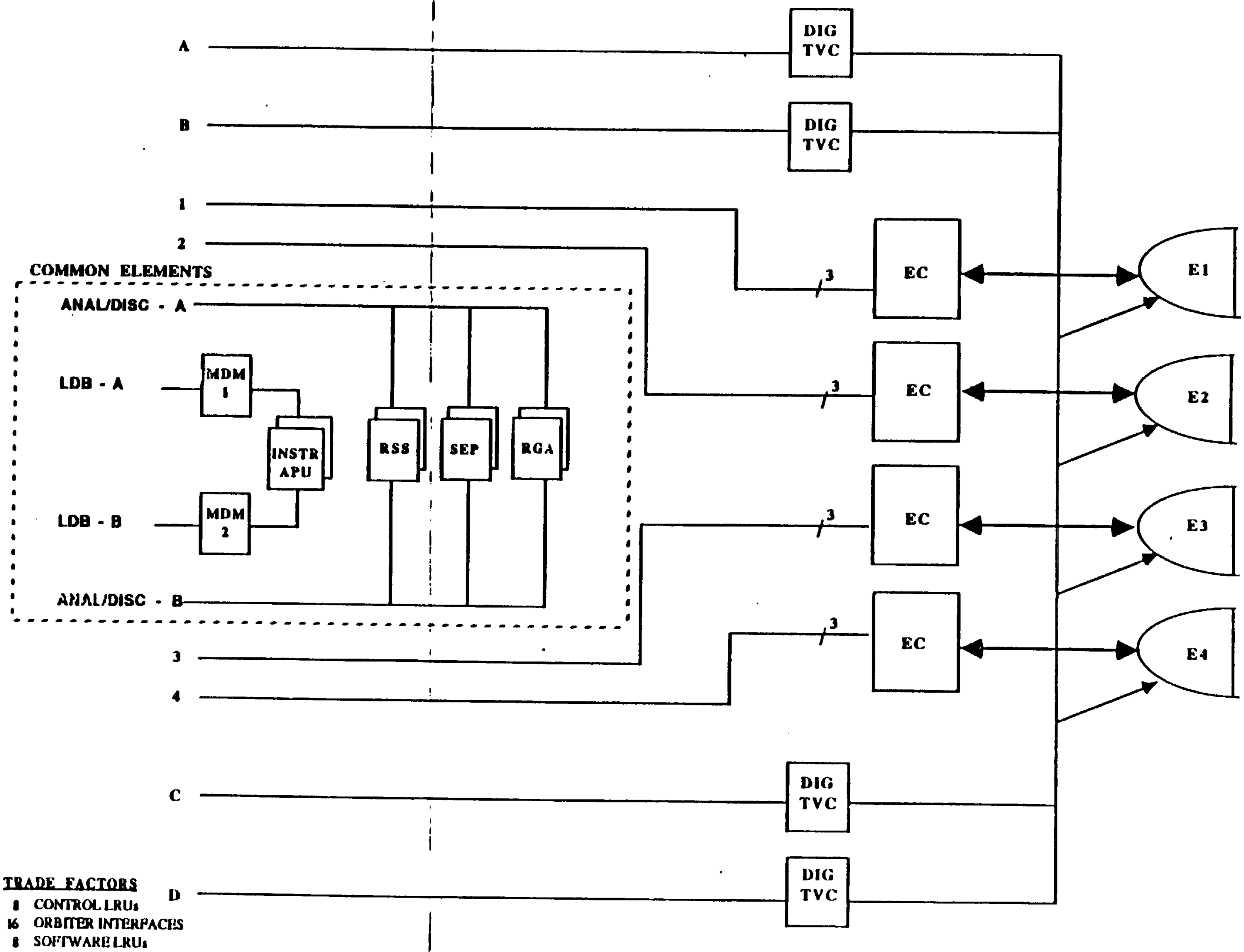

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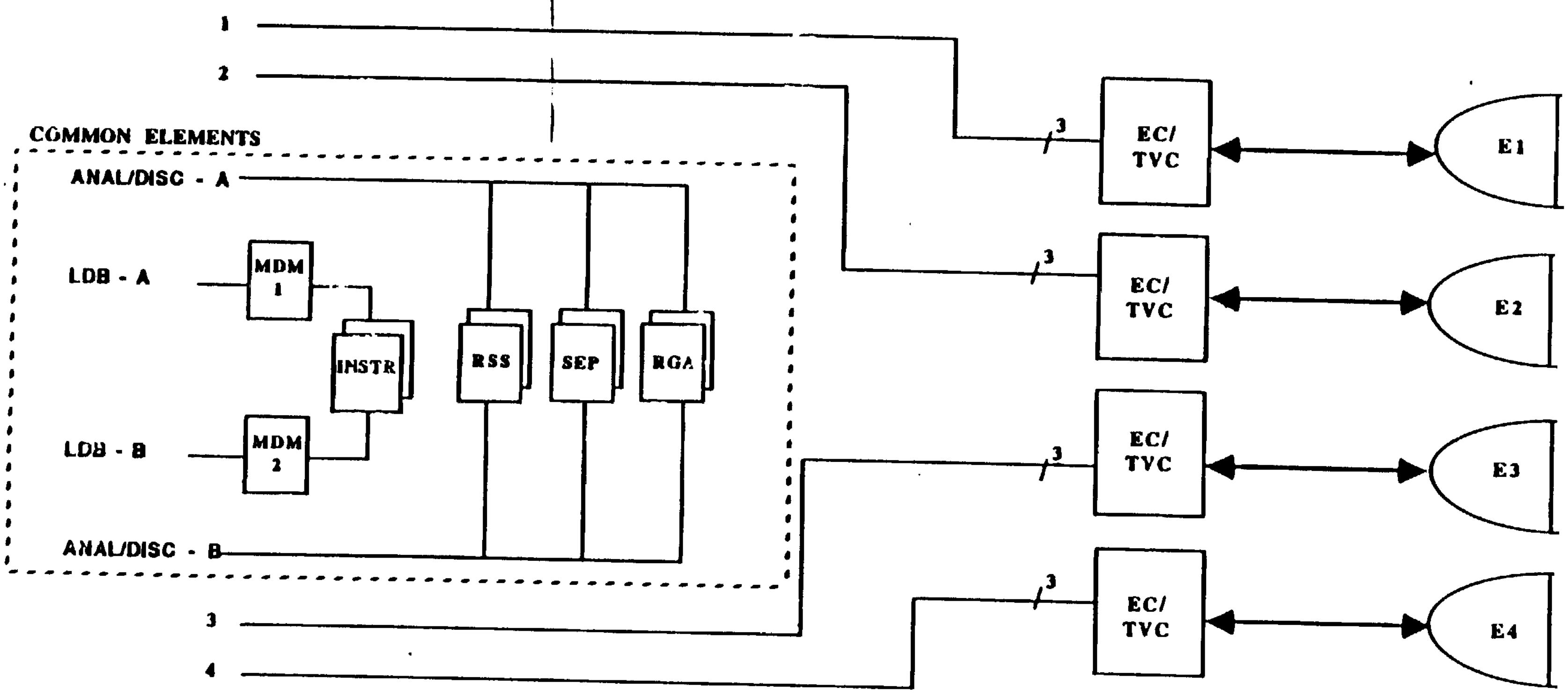
560 WEIGHT (LB)

BJM103D

DISTRIBUTED (PRESSURE)



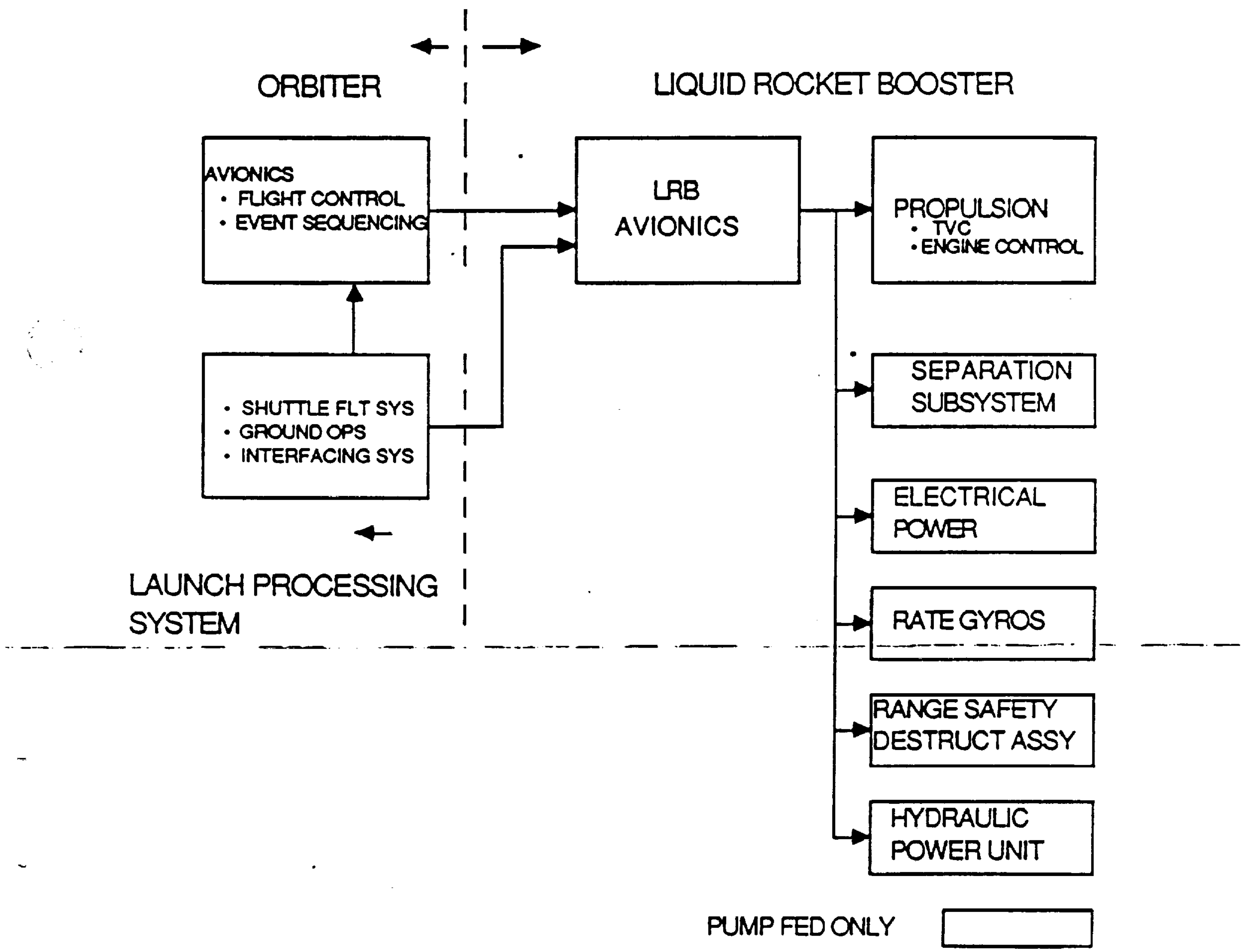
TRADE FACTORS

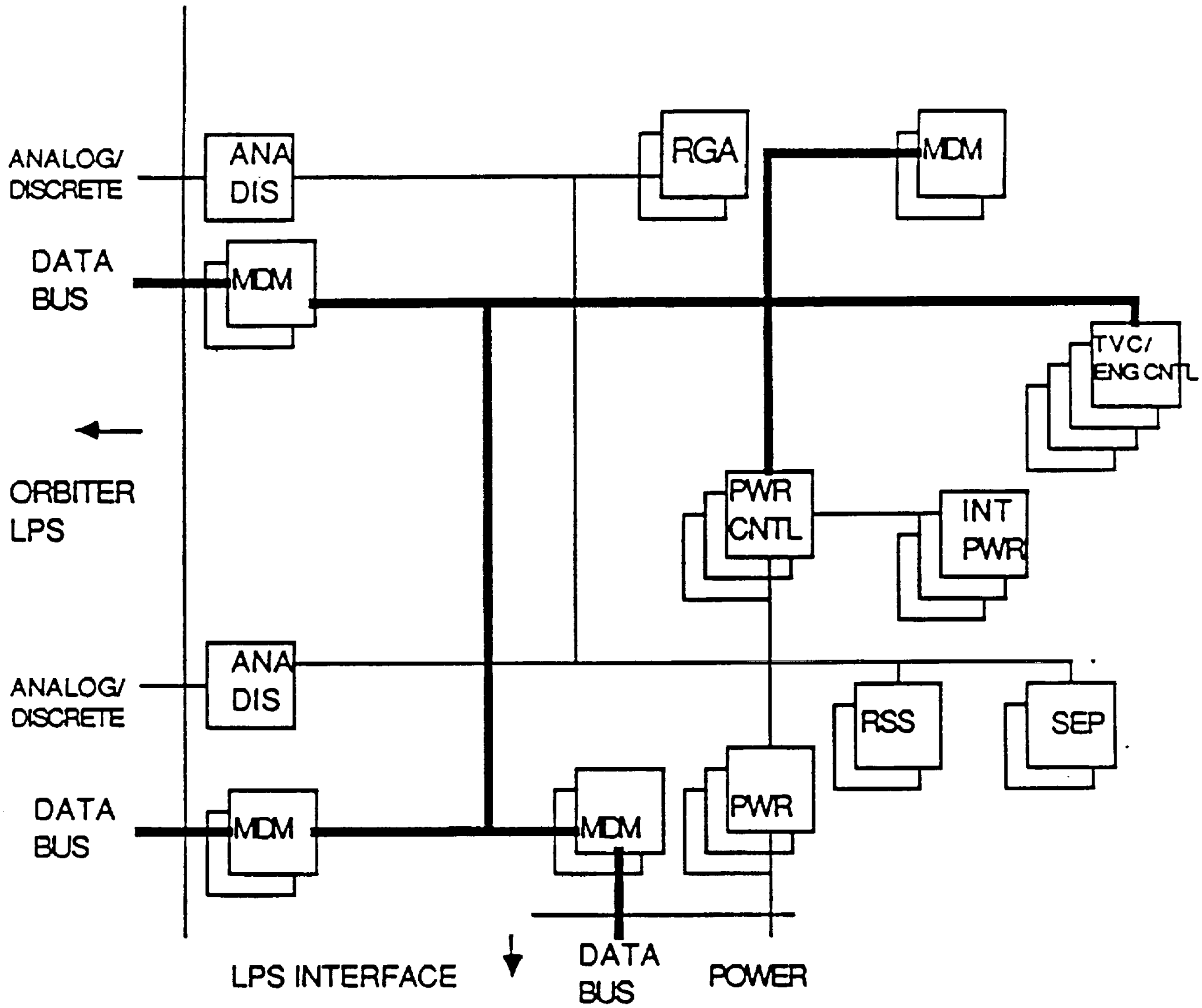
4 CONTROL LRUs
12 ORBITER INTERFACES
4 SOFTWARE LRUs
400 WEIGHT (LB)

BJM103D

EXPENDABLE LRB, EXPENDABLE LRB AVIONICS

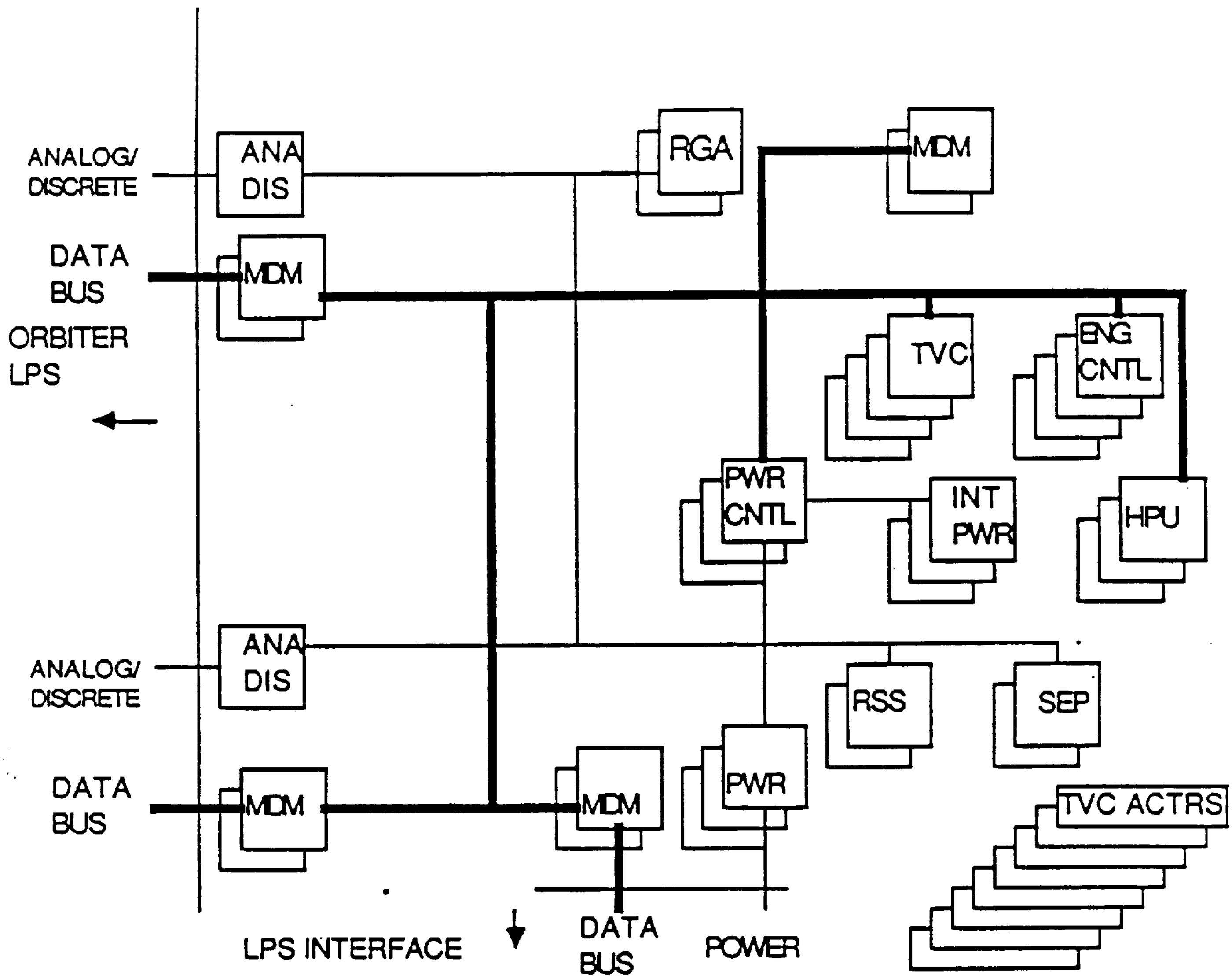
INTERFACE BLOCK DIAGRAM





EXPENDABLE PRESSURE FED LIQUID INJECT TVC

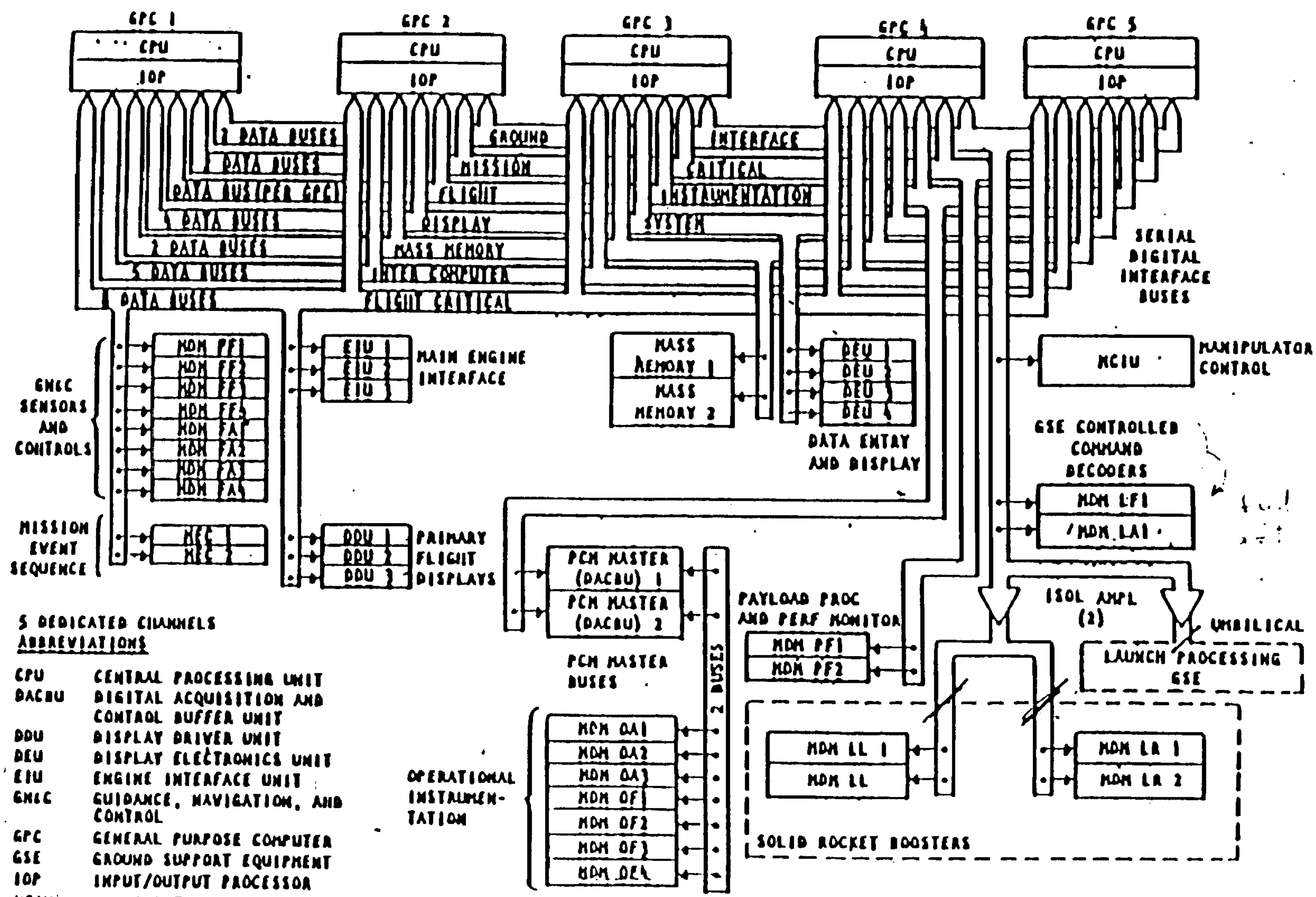
LRU	WT(lbs)	PWR(W)	QUANT	TOTAL WT(lbs)	TOTAL PWR(W)
			TOTAL		



EXPENDABLE PUMP FED HYDRAULIC ACTUATORS

LRU	WT(lbs)	PWR(W)	QUANT	TOTAL WT(lbs)	TOTAL PWR(W)
			TOTAL		

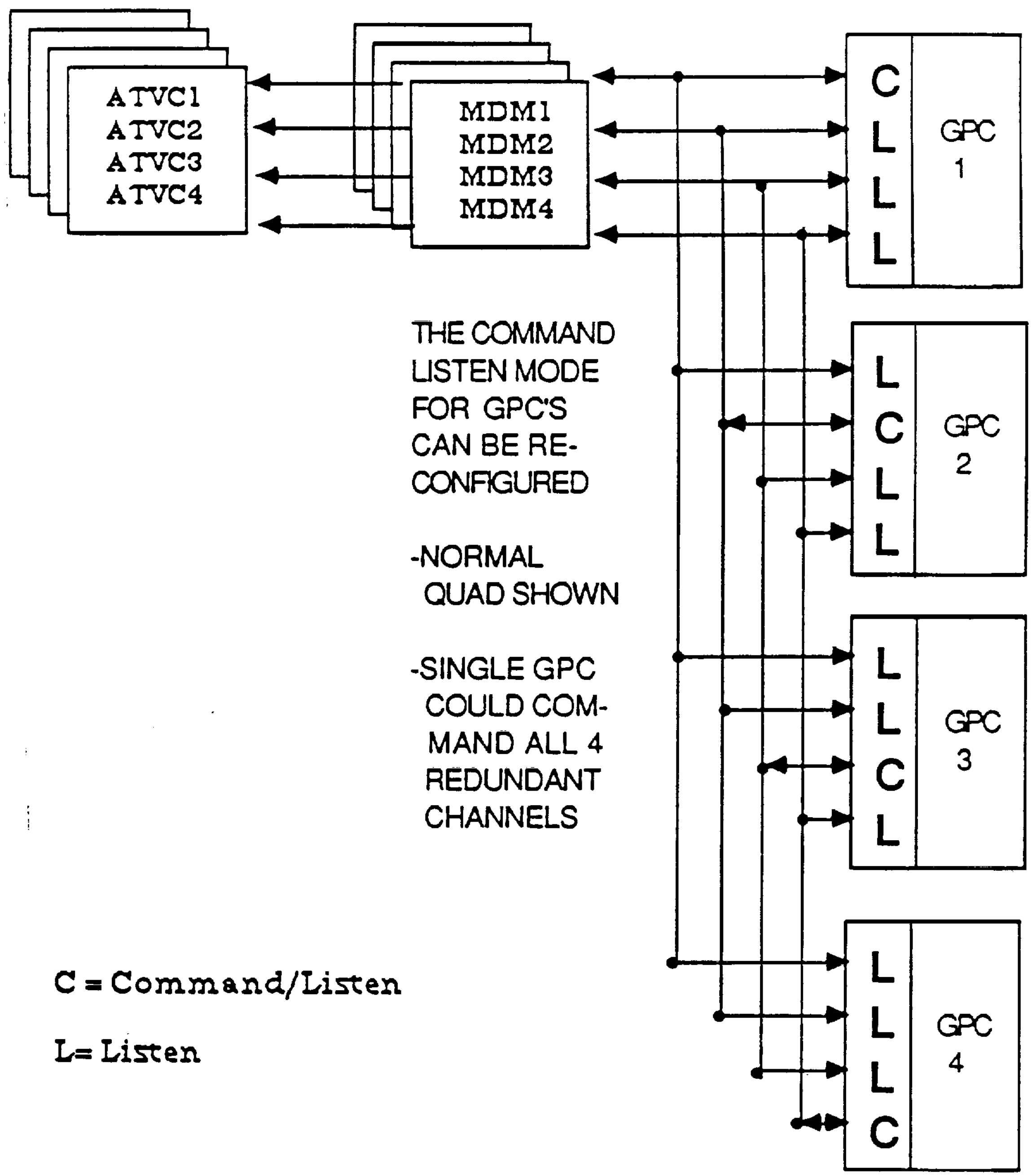
BLOCK DIAGRAM OF DATA PROCESSING SUBSYSTEM



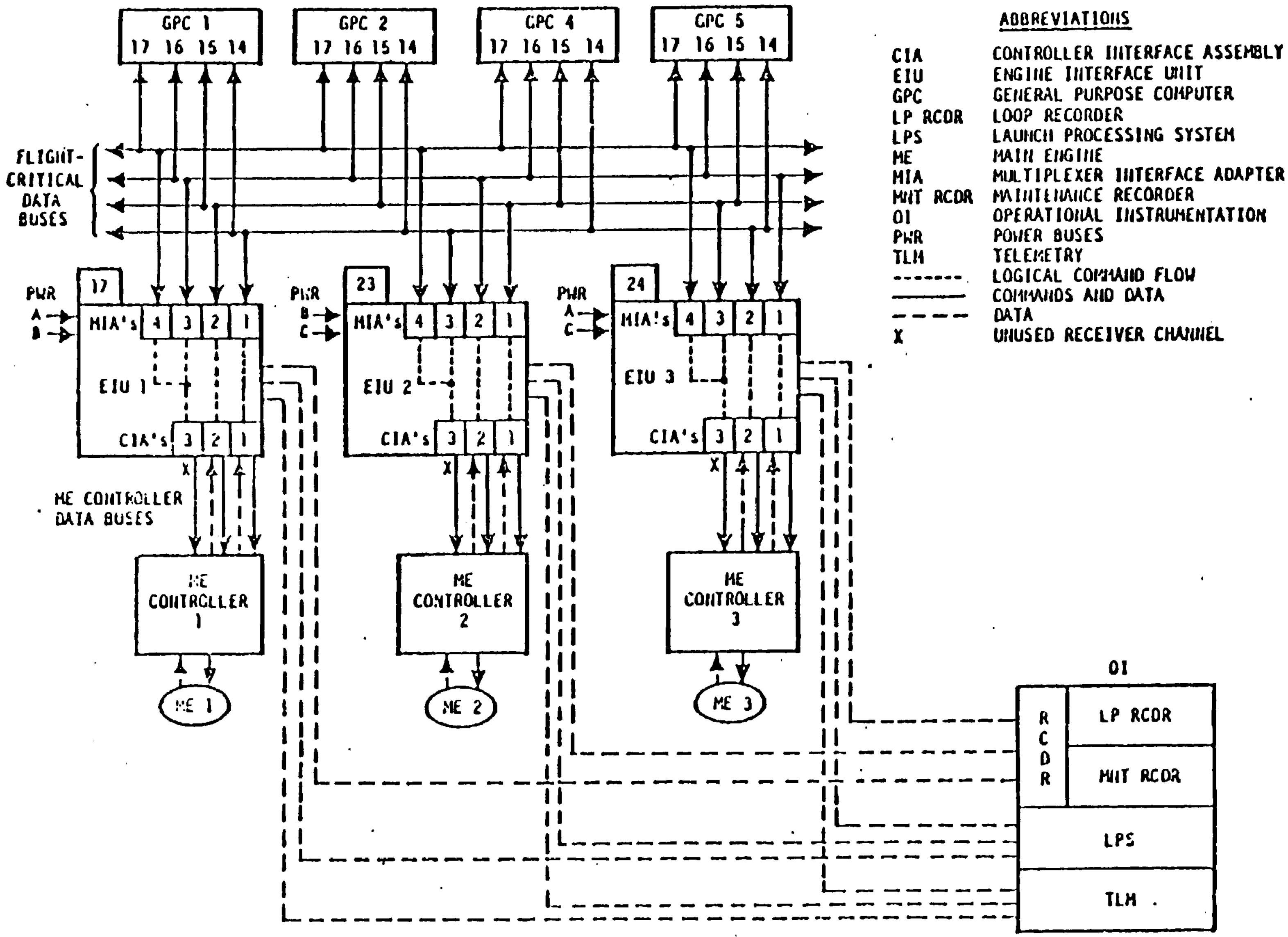
5 DEDICATED CHANNELS

ABBREVIATIONS

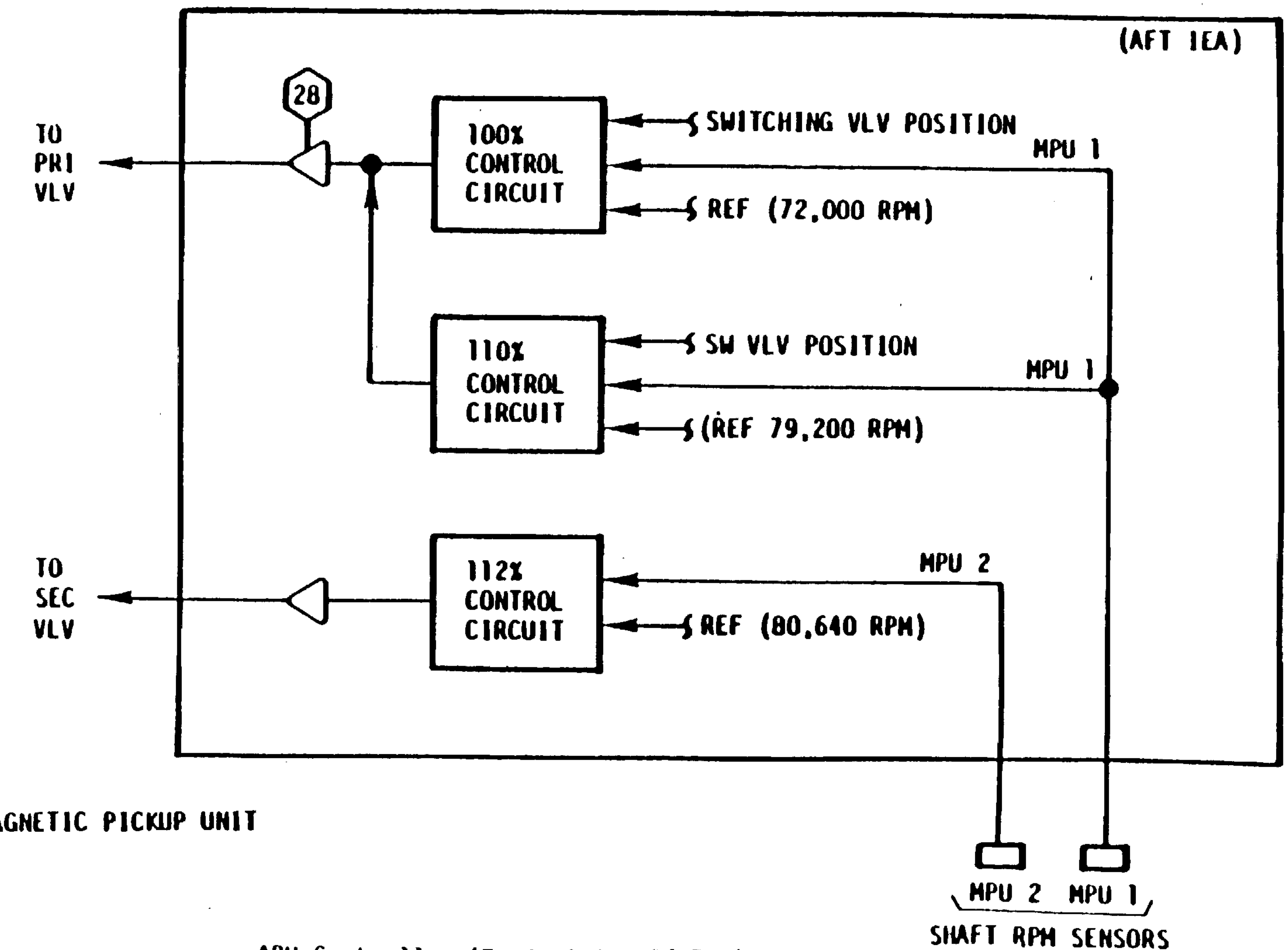
CPU	CENTRAL PROCESSING UNIT
DACBU	DIGITAL ACQUISITION AND CONTROL BUFFER UNIT
DDU	DISPLAY DRIVER UNIT
DEU	DISPLAY ELECTRONICS UNIT
EIU	ENGINE INTERFACE UNIT
GN&C	GUIDANCE, NAVIGATION, AND CONTROL
GPC	GENERAL PURPOSE COMPUTER
GSE	GROUND SUPPORT EQUIPMENT
IOP	INPUT/OUTPUT PROCESSOR
MCIU	MANIPULATOR CONTROLLER INTERFACE UNIT.
MDM	MULTIPLEXER/DEMULTIPLEXER
PCM	PULSE CODE MODULATION



COMPUTER/DATA BUS CONFIGURATION



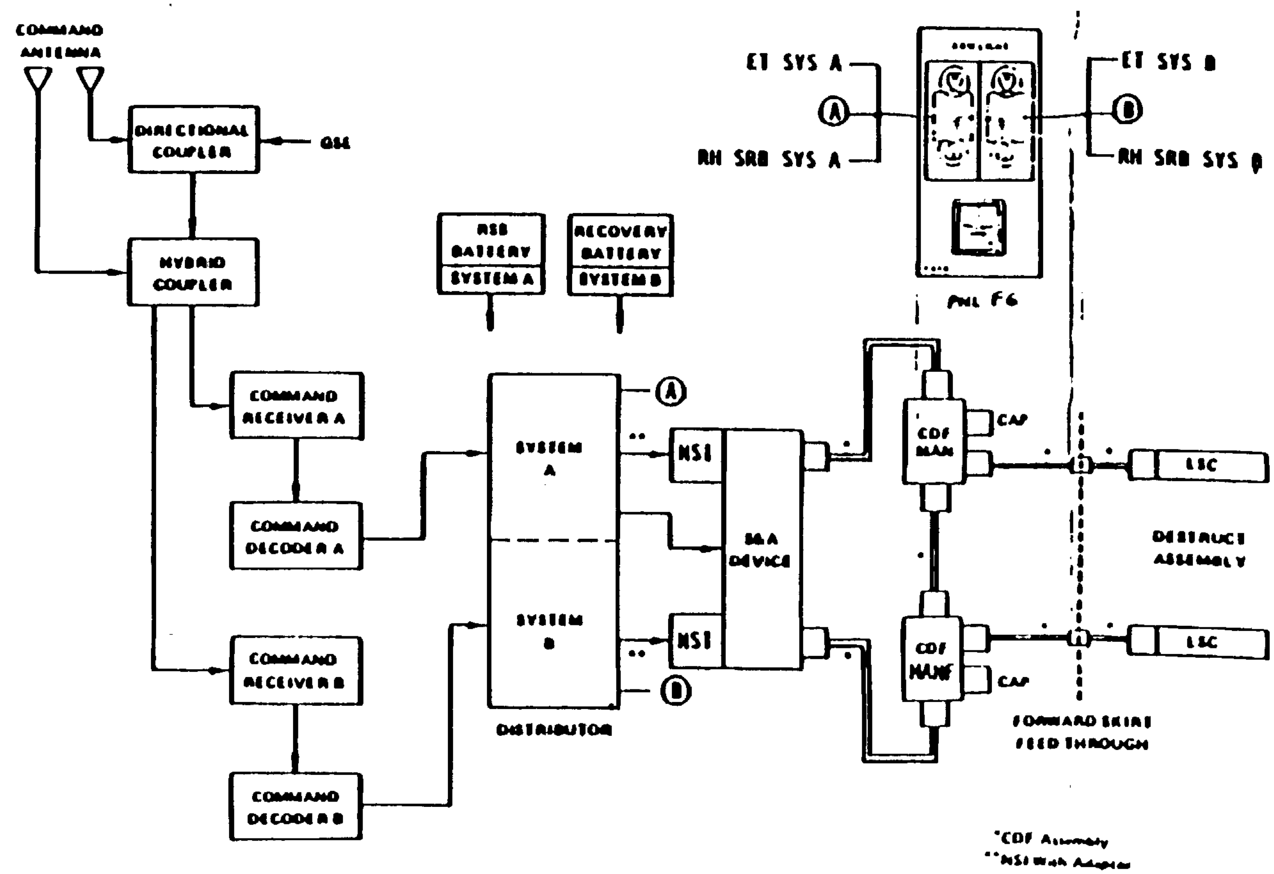
EIU Interface Configuration



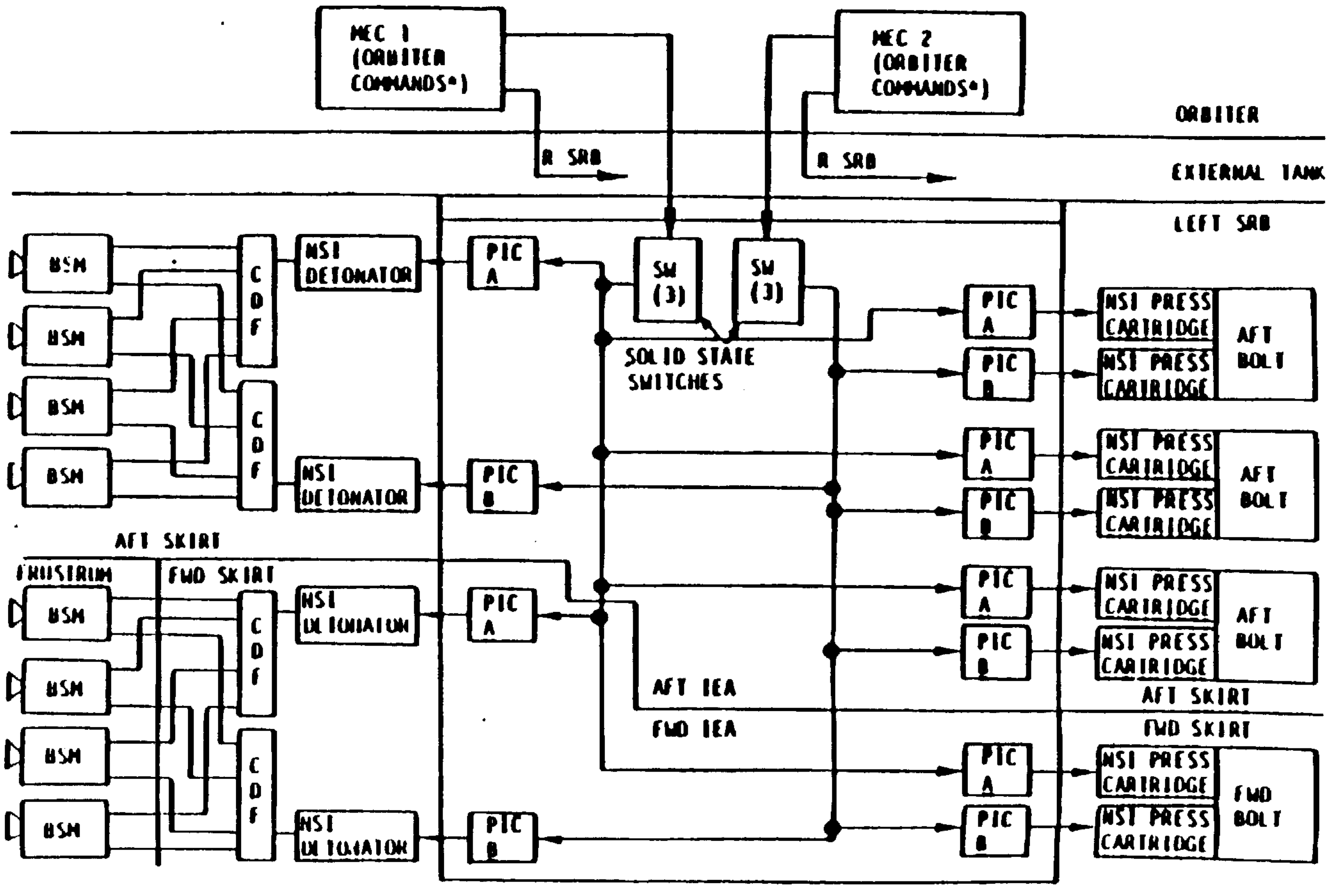
MPU = MAGNETIC PICKUP UNIT

APU Controller (Typical One Of Two)

Preliminary



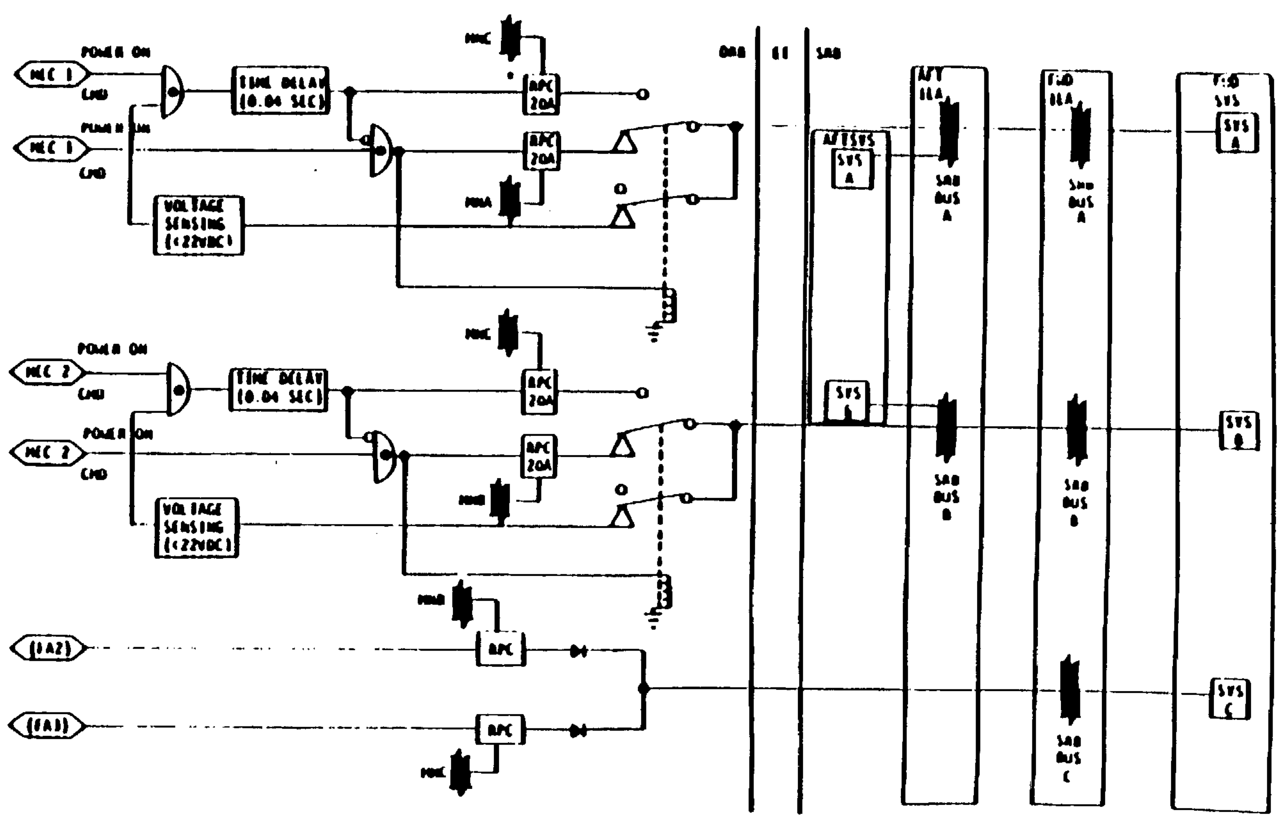
SRB RSS



*SEPARATION COMMANDS: ARM, FIRE 1, FIRE 2

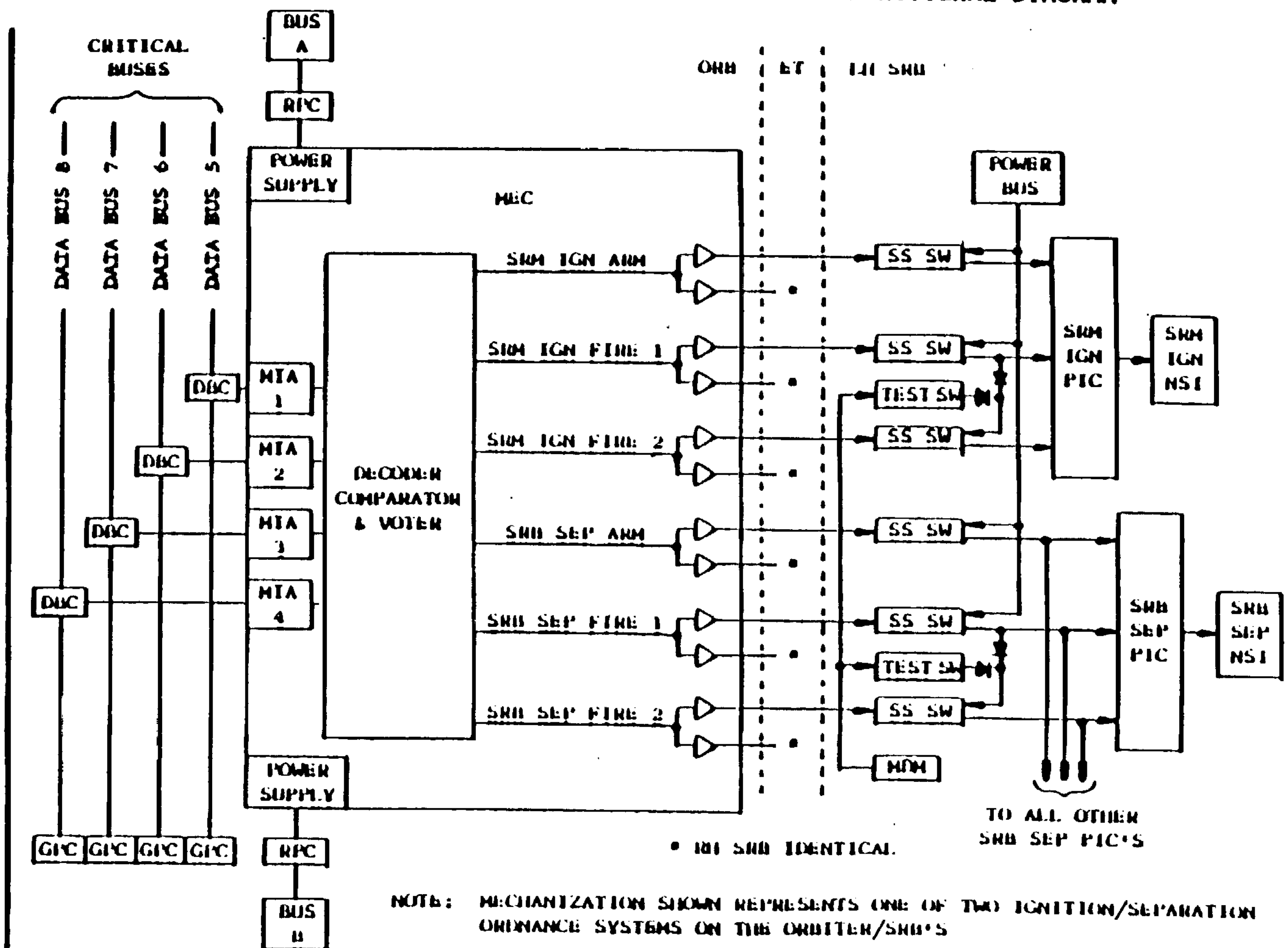
SRB Separation Sequence PIC's

Preliminary



SRB Electrical Power Distribution

TYPICAL IGNITION/SEPARATION ORDNANCE SYSTEM FUNCTIONAL DIAGRAM



NOTE: MECHANIZATION SHOWN REPRESENTS ONE OF TWO IGNITION/SEPARATION ORDNANCE SYSTEMS ON THE ORBITER/SRB'S

EXPENDABLE/REUSABLE TRADE STUDY

Expendable and reusable approaches to avionics mechanization are considered. Locating LRB avionics on the orbiter to achieve reusability is not a practical alternative due to greatly increased interface wiring requirements that would be the result. Packaging avionics to be separately jettisoned is also not practical due to electrical interface disconnect problems. It is also doubtful that a more benign recovery environment would be achieved by jettisoning.

Cost of reusable avionics would be a minor increase over current STS avionics mechanization costs. Environment seals and chassis structures would need to be improved. Costs of expendable avionics LRUs would not be much less than reusable LRUs as long as LRB avionics are required to be man-rated. No appreciable cost reduction will be achieved unless class "S" requirements are removed in recognition of a short mission life.

STS Integration Impacts

No difference (unless functions can be moved to orbiter.)

Life Cycle Costs

- Very little DDT&E differences to upgrade hardware from shuttle requirements.

- Expendable hardware will not be much cheaper as long as class "S", man-rated, and redundancy requirements remain. test effort may be slightly reduced.

- Cost of refurbishment is minor

		E	R
DDT&E		.9	1
	Score	(10)	(9)
Production		1	.1
	Score	(1)	(10)
Support		.9	1
	Score	(10)	(9)
		(21)	(28)
		7	10

Performance

-No difference.

Launch Fa~~a~~c/Ground Impact

Refurbishment and retest of electronics will be minor and probably performed at vendor facility.

? NOT TO THE NAVY!

	E	R
Score	10	9

Operational Complexity

-No difference.

Weight

Reusable may require a stronger structure, less than 10% difference.

	E	R
Structure	.9	1
Score	$\boxed{10}$	$\boxed{9}$

Maintainability

-No difference.

Technical Risk

Reusable add risk of inadequate refurbishment.

E	R
10	9

Test Requirements

-Additional quality test requirements on reusable electronics.

		E	R
Testing		.9	1
	Score	10	9

Growth/Evolution

-No difference.

Future Applications

-No difference.

THE SRB RECOVERY SYSTEM

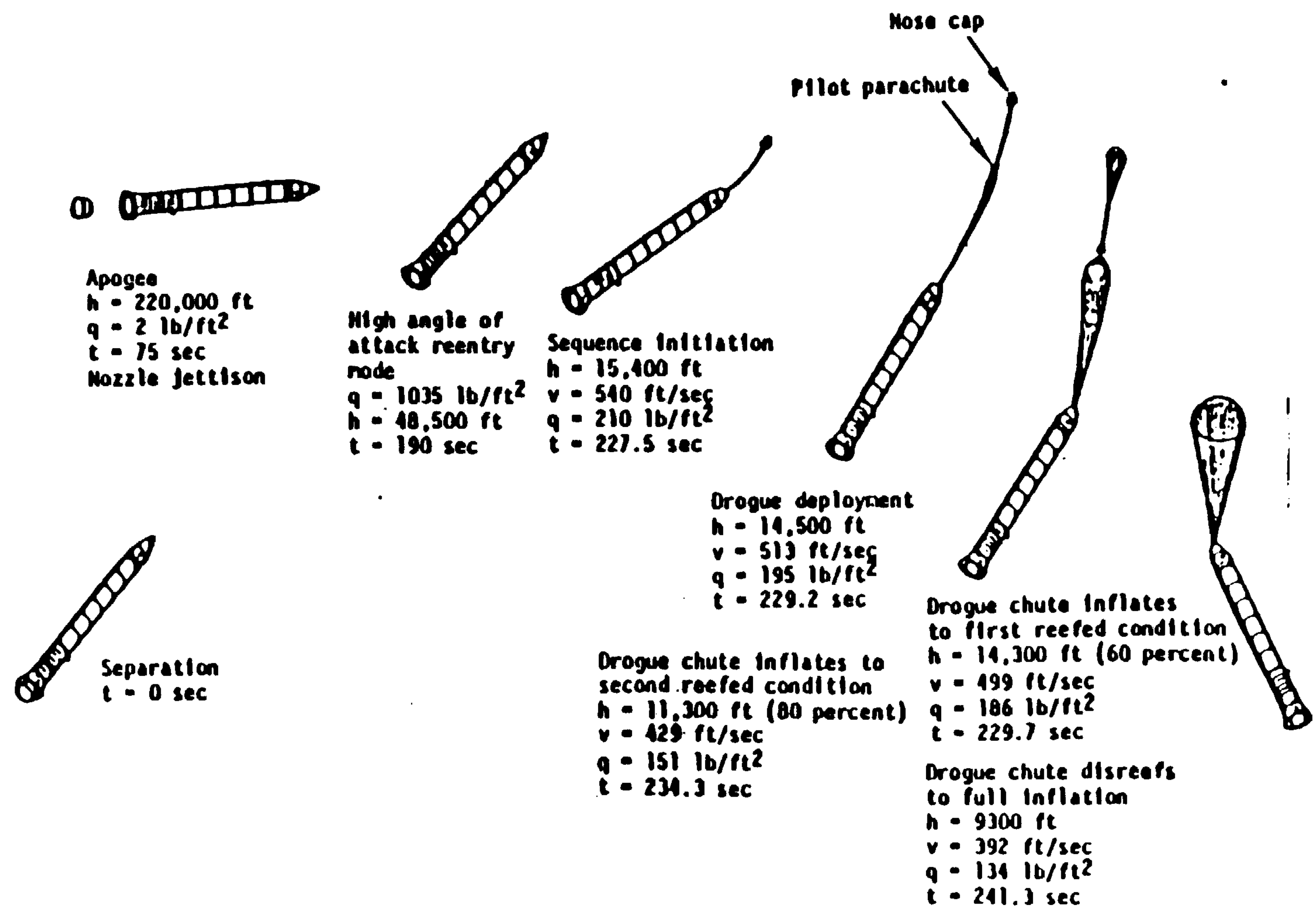
- WITHOUT A RECOVERY SYSTEM, THE SRBs WOULD IMPACT AT 500 TO 600 FT/SEC
- WITH THE PARACHUTES, THE SRBs IMPACT AT 85 TO 95 FT/SEC
- SEPARATION OF THE FRUSTRUM ALLOWS THE DEPLOYMENT OF THE SRB MAIN PARACHUTES

  --THE MAIN PARACHUTES ARE STORED IN THE FRUSTRUM

  --THE FRUSTRUM IS RECOVERED (IT HAS ITS OWN BATTERY POWERED LOCATION AIDS)

  --THE FRUSTRUM IS SEPARATED FROM THE SRB BY A LINEAR SHAPED CHARGE
- A LINEAR SHAPED CHARGE SEPARATES THE NOZZLE AFT EXIT CONE AFTER BURNOUT

  --TO PREVENT DAMAGE TO THE NOZZLE BEARING AT IMPACT

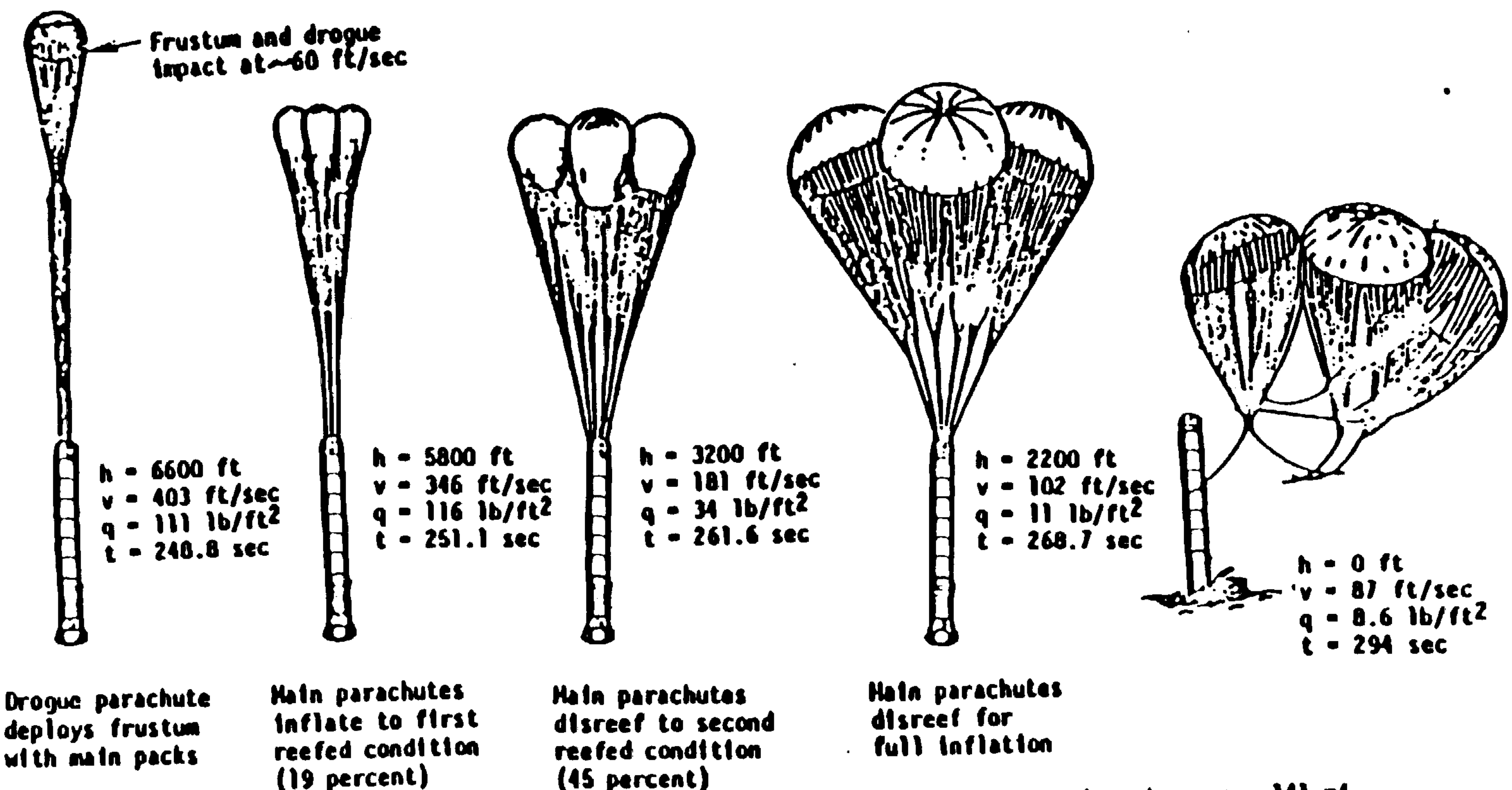


SRB Postseparation Sequence (Part 1)

Preliminary

Johnson Space Center - Houston, Texas

SRB SYSTEMS FUNCTIONAL DESCRIPTION	Advanced Programs Office	
	K.Holden/LEMSCO	9/30/87



- o SRB water impact range - 141 mi.
- o Footprint - 6 by 9 n.mi. (both boosters)
- o Detach parachutes at impact
- o Deploy towing pendant

SRB Postseparation Sequence (Part 2)

RECOVERY SUBSYSTEMS

- CONSTRAINTS
  - --SRB NOMINAL APOGEE SHALL NOT EXCEED
    - o 255,000 FT FOR MIDWEIGHT SRB
    - o 260,000 FT FOR LIGHTWEIGHT SRB
    - o (EXCEEDING APOGEE LIMITS WILL REDUCE RECOVERY PROBABILITY BELOW 99%)
  - --SEA-STATE
    - o SEA-STATE FOR SRB FLOTATION MUST NOT EXCEED SEA-STATE CODE 5 (SRB FLOTATION OF AT LEAST 72 HOURS REQUIRED)
    - o SEA-STATE FOR RETRIEVAL AND TRANSPORTATION MUST NOT EXCEED SEA-STATE CODE 4

- PARACHUTE

--LIMIT LOADS:	PILOT	=	14,515 LBf
	DROGUE	=	270,000 LBf
	MAINS	=	521,000 LBf
--DIAMETER:	PILOT	=	11.5 FT
	DROGUE	=	54 FT
	MAIN (EACH)	=	115 FT

RECOVERY SUBSYSTEMS (CONTD)

- RECOVERY BATTERY
  --ONE PER SRB
  --TYPE IS SILVER/ZINC
  --CAPACITY IS 60 AMP-HR
  --USEFUL LIFE - 1 FLIGHT

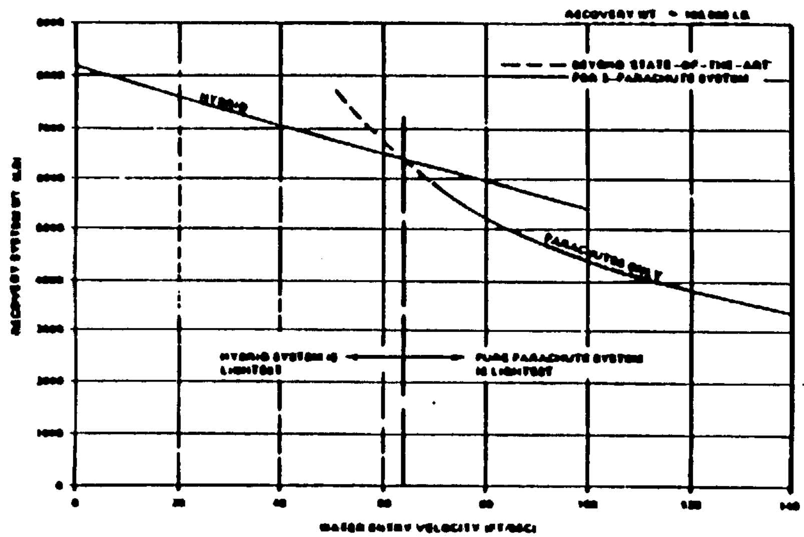
Preliminary

Johnson Space Center - Houston, Texas

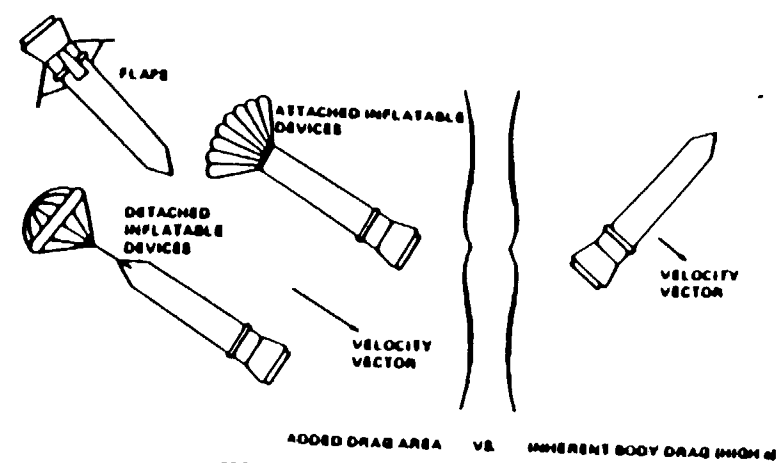
SRB SYSTEMS FUNCTIONAL DESCRIPTION	Advanced Programs Office	
	K.Holden/LEMSCO	9/30/87

SRB RECOVERY SYSTEMS DEVELOPMENT

- ACTIVE ATTITUDE CONTROL SYSTEMS WERE ELIMINATED TO MINIMIZE COST AND COMPLEXITY OF RECOVERY SYSTEMS
- AN ALL PARACHUTE FINAL BRAKING SYSTEM WAS SELECTED
  - --AN ALL PARACHUTE SYSTEM WAS LIGHTER THAN A HYBRID ROCKET/PARACHUTE SYSTEM IF WATER IMPACT VELOCITY WAS ABOVE 65 FT/SEC
  - --STUDIES OF WATER IMPACT HAD CONCLUDED THAT A 80 TO 100 FT/SEC TAIL FIRST IMPACT SYSTEM WOULD PROVIDE A GOOD COMPROMISE BETWEEN INITIAL IMPACT AND SLAP DOWN LOADS
- THE HIGH ALTITUDE BOOSTER DECELERATION
  - --PROVIDE ACCEPTABLE VELOCITY FOR PARACHUTE DEPLOYMENT
  - --METHOD OF DECELERATION SELECTED WAS TO HAVE THE SRB AERODYNAMICALLY STABLE IN A HIGH ANGLE OF ATTACK (BROADSIDE) REENTRY MODE
  - --SRB CG AT 53% BODY LENGTH FROM SRB NOSE WOULD CAUSE THE SRB TO TRIM IN THIS ATTITUDE
  - --A FURTHER AFT CG WOULD CAUSE THE BOOSTER TO TRIM IN A SOMEWHAT TAIL FIRST AND LOWER DRAG ATTITUDE
- A RESULT OF THE REENTRY ANALYSIS WAS THE ESTABLISHMENT OF A BOOSTER CG AFT LIMIT FOR RECOVERY SYSTEM DESIGN PURPOSES
  - --FINAL SELECTION OF A 59% AFT LIMIT WAS A COMPROMISE BETWEEN SRB WEIGHT DISTRIBUTION AND ACCEPTABLE CONDITIONS FOR DROGUE DEPLOYMENT



Deceleration System Weight.



SRB High Altitude Deceleration Concepts.

RETRIEVED FLIGHT HARDWARE - REPLACEMENT COSTS*

MISSION STS	SRB		MAIN PARACHUTES								FRUSTUM		
	RIGHT	LEFT	1	2	3	4	5	6	RIGHT	LEFT	RIGHT	LEFT	
1	25M	25M	65K	65K	65K	65K	—	—	50K	50K	1.5M	1.5M	53.36M
2	25M	25M	65K	65K	65K	65K	65K	—	50K	50K	1.5M	1.5M	53.425M
3	25M	25M	65K	65K	65K	65K	65K	—	50K	50K	1.5M	1.5M	53.425M
4	—	—	—	—	—	—	—	—	50K	50K	1.5M	1.5M	3.1M
5	25M	25M	65K	65K	65K	65K	65K	65K	50K	50K	1.5M	1.5M	53.49M
TOTALS	100M	100M	260K	260K	260K	260K	195K	65K	250K	250K	7.5M	7.5M	216.8M

* COST DATA PROVIDED BY MSFC, APRIL 1983

DAN CALLAN (1-15-88)

Assuming 9 flights / year (could go to 12 or 14)
x 2 LRBs / flight
x 10 year lifetime
180 Expendable LRBs

If Reusable:
approx 4 months to refurbish
∴ need 3 sets to cover a year
+ 1 set for spares
4 x 2 LRBs/set = 8 LRBs needed

$8 \overline{)180}$ 22 to 1 production ≈ 0.6

	E	R
normalizing to digit	10	1

TVC AVIONICS TRADE STUDY

Fluid injector, Hydraulic actuator, and Electromagnetic actuator thrust vector control avionics mechanizations are considered for the LRB. Hydraulic actuators are on the current SRB. The required hydraulic system support would be nice to avoid.

Fluid injection is not a new, but infrequently used technique. The only large scale use known is the Titan III solid rocket booster. Valves (24) are driven by a servo motor control loop. Equivalent gimbal deflection capability is suspect.

Electromagnetic actuators would eliminate the requirement for hydraulic support or extra fluid weight. However, as far as the avionics is concerned, it will require the most development and requires the most complex on board mechanization. Since this trade is concerned with the avionics only, an EMA approach compares unfavorably.

DDT&E Costs

Function of LRU types and amount of development required.

	F	H	E
LRU Types	1	1	2
Score	(10)	(10)	(5)
Development	(5)	(10)	(2)
	15	20	7
Total Score	8	10	4

Life Cycle Costs

Function of DDT&E costs, production (LRU count) costs, and operations cost

	F	H	E
DDT&E	(8)	(10)	(4)
LRU Count	4	4	12
Score	(10)	(10)	(3)
Ground Operations (Hydraulic Support)	(5)	(5)	(10)
	23	25	17
	9	10	7

Operational Complexity

Function of requirements for supporting systems (Hydraulic, power)

F	H	E
10	5 (Hydr.)	8 (Ground Pwr)

Performance

Hyd: Best (proven)

F. I.: Worst (LIMITED GIMBALLING)

EMA: Uncertain, not fully developed

F	H	E
4	10	6

Weight

Avionics only weight (w/o batteries)

	F	H	E
Weight	160	160	320
score	10	10	5

Recovery/Reusability

LRUs to be recovered

	F	H	E
LRU count	4	4	12
score	(10)	(10)	(3)

Safety/Reliability

Need for Hydraulic system reduces safety faction?

- Doesn't affect electronics safety

More LRUs reduces reliability

AVIONICS ONLY	F	H	E
LRU count	4	4	12
score	(10)	(10)	(3)

Size

LRU count

F	H	E
10	10	3

Technical Risks

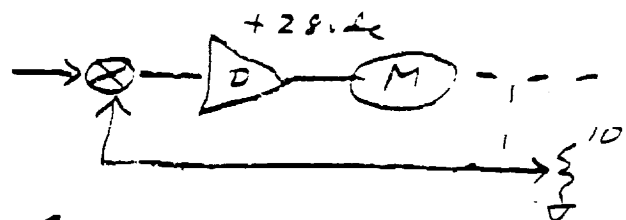
- EMA Technology development ~5
- Fluid injection performance ~8

F	H	E
8	10	5

Bill Hoffman Telecon 1-13-88

- fluid injection valves use a +28 vdc ~~motor~~ driven ball screw

- Motor is included in a servo loop that requires 0-10 vdc drive signal



- 0.25 second full open to full close

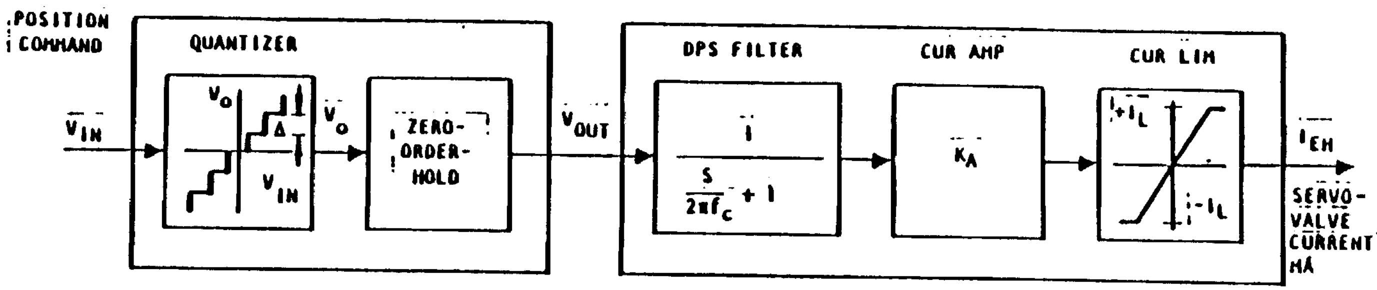
- 6 to 7 amps motor line current

- 1960's Technology

- These are used on a fluid injection system for a 1.2M solid rocket booster for Titan III

- Fluid injection removes need for gimbaled ball clearance between engines or fairing skirt thereby reducing drag
  - reduced drag pays for weight of steering fluid.

BLOCK DIAGRAM OF SERVOACTUATOR COMMAND CHARACTERISTICS



QUANTIZER

$$V_O = \text{INTEGER}\left(\left|\frac{V_{IN}}{\Delta}\right| + 0.5\right) \Delta \text{ SIGN } (V_{IN})$$

$\Delta = 0.010$ VOLT

ZERO-ORDER HOLD (VOLTAGE CLAMP)

$$G(S) = \frac{V_{OUT}}{V_O} = \frac{1-e^{-TS}}{S}$$

SAMPLING RATE, $\frac{1}{T} = 25$ Hz

MDM VOLTAGE OUTPUT (V_{OUT})

MAXIMUM V_{OUT} = +5.11 V, -5.12 V

DPS FILTER

$f_C = 8.7$ Hz

CURRENT AMPLIFIER

$K_A = 11.0$ MA/VOLT

CURRENT LIMITER MAXIMUM

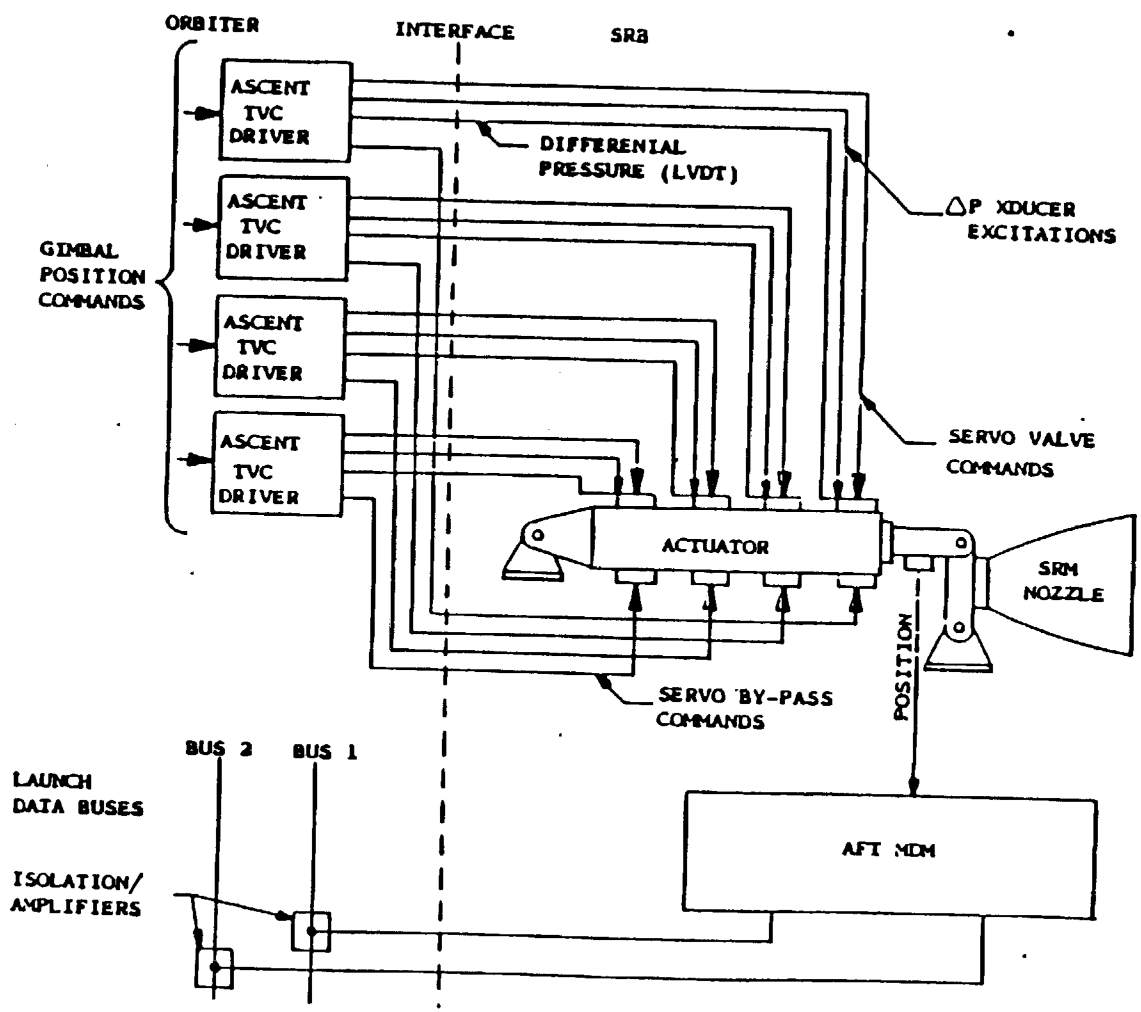
$I_L = 55.0$ MA

Preliminary

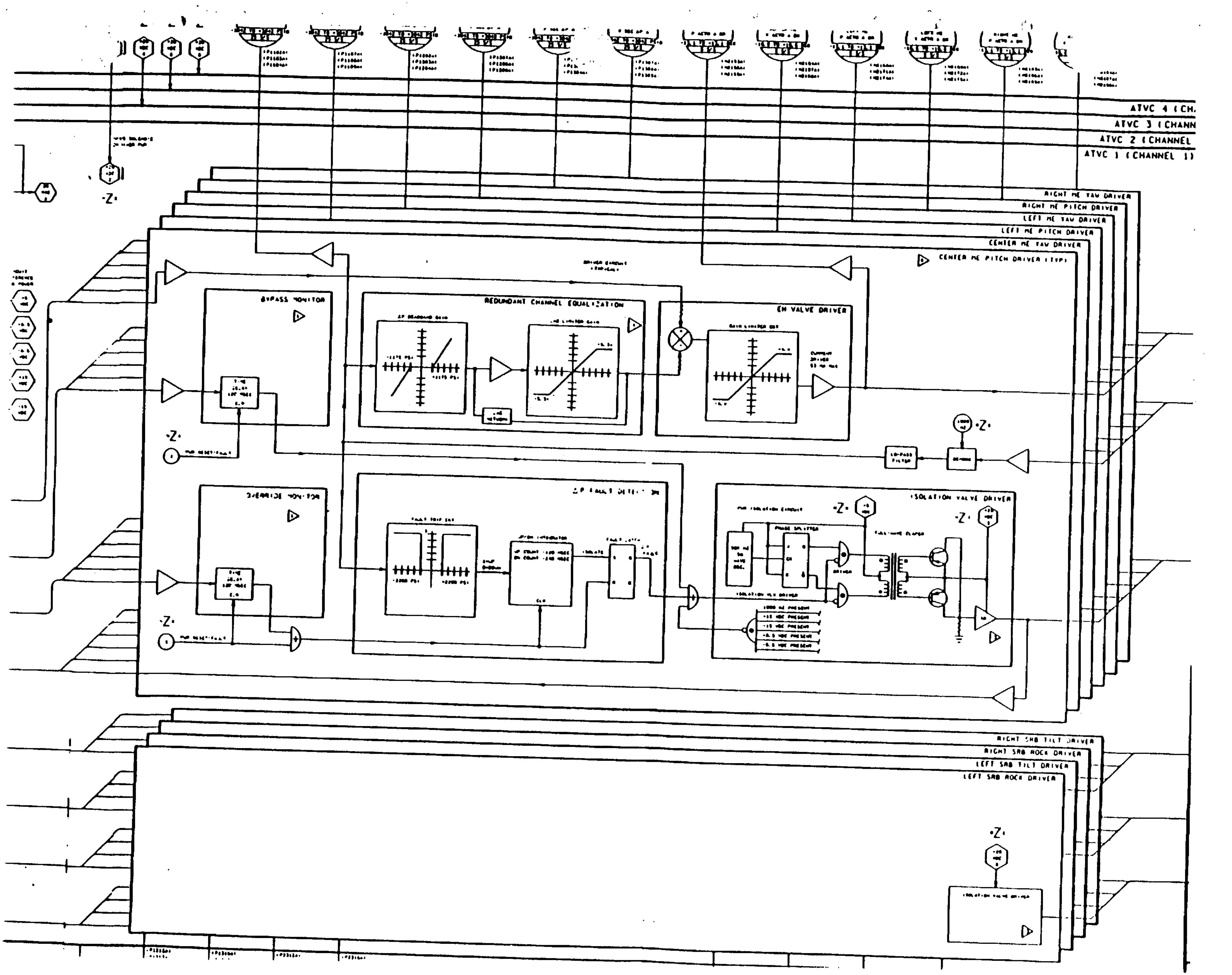
ORBITER SYS FUNCTIONAL DESCRIPTION	Advanced Programs Office	
	J.Klinar/LEMSCO	9/30/87

Johnson Space Center - Houston, Texas

SRM NOZZLE GIMBAL CONTROL FUNCTIONAL INTERFACE DIAGRAM

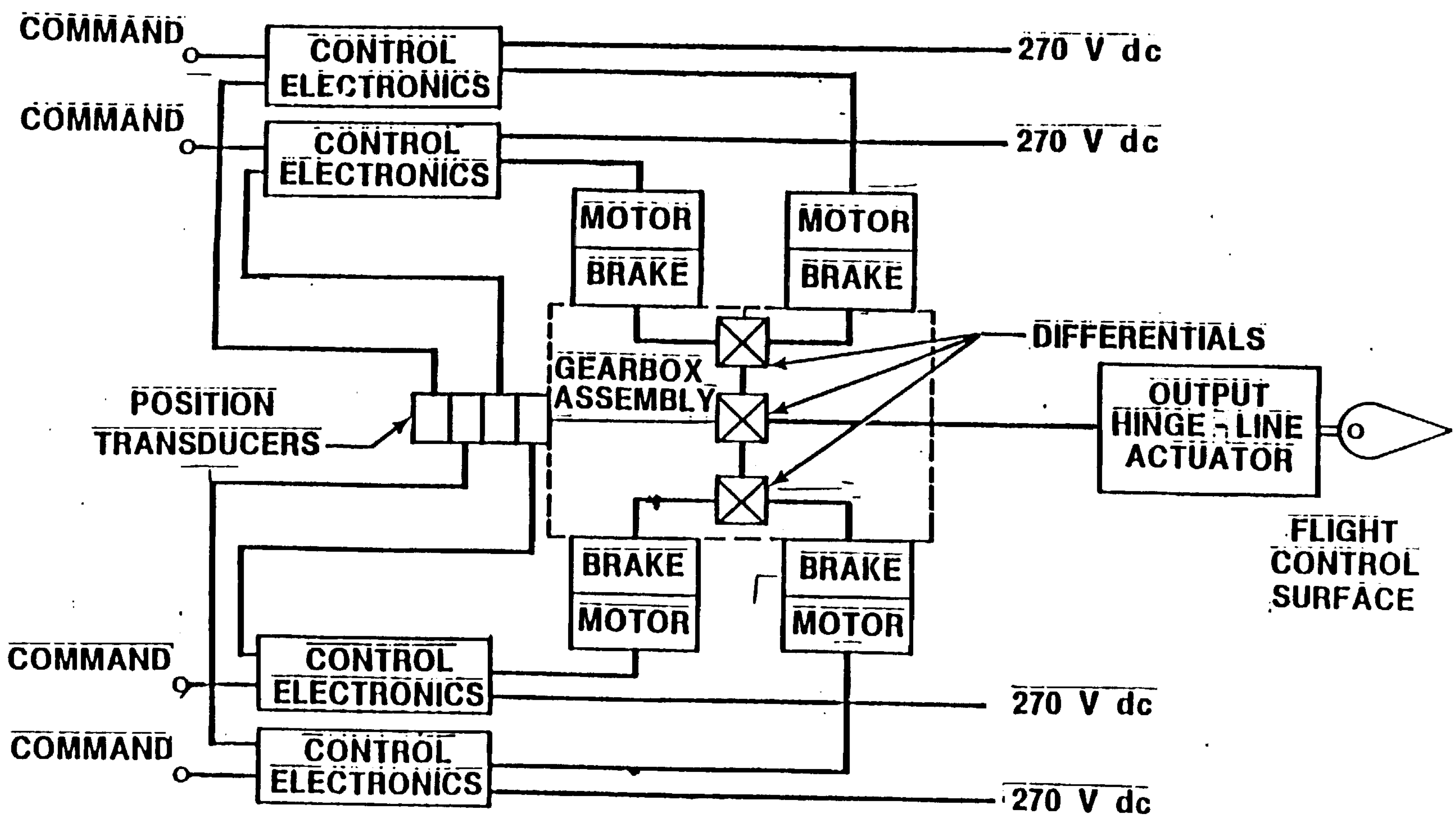


10


ATVC 4 (CH.
ATVC 3 (CHANN
ATVC 2 (CHANNEL
ATVC 1 (CHANNEL 1)
RIGHT ME YAW DRIVER
RIGHT ME PITCH DRIVER
LEFT ME YAW DRIVER
LEFT ME PITCH DRIVER
CENTER ME YAW DRIVER
CENTER ME PITCH DRIVER (TYP)
BYPASS MONITOR
REDUNDANT CHANNEL EQUALIZATION
EH VALVE DRIVER
OVERRIDE MONITOR
ISOLATION VALVE DRIVER
-Z-
RIGHT SRB TILT DRIVER
RIGHT SRB ROCK DRIVER
LEFT SRB TILT DRIVER
LEFT SRB ROCK DRIVER

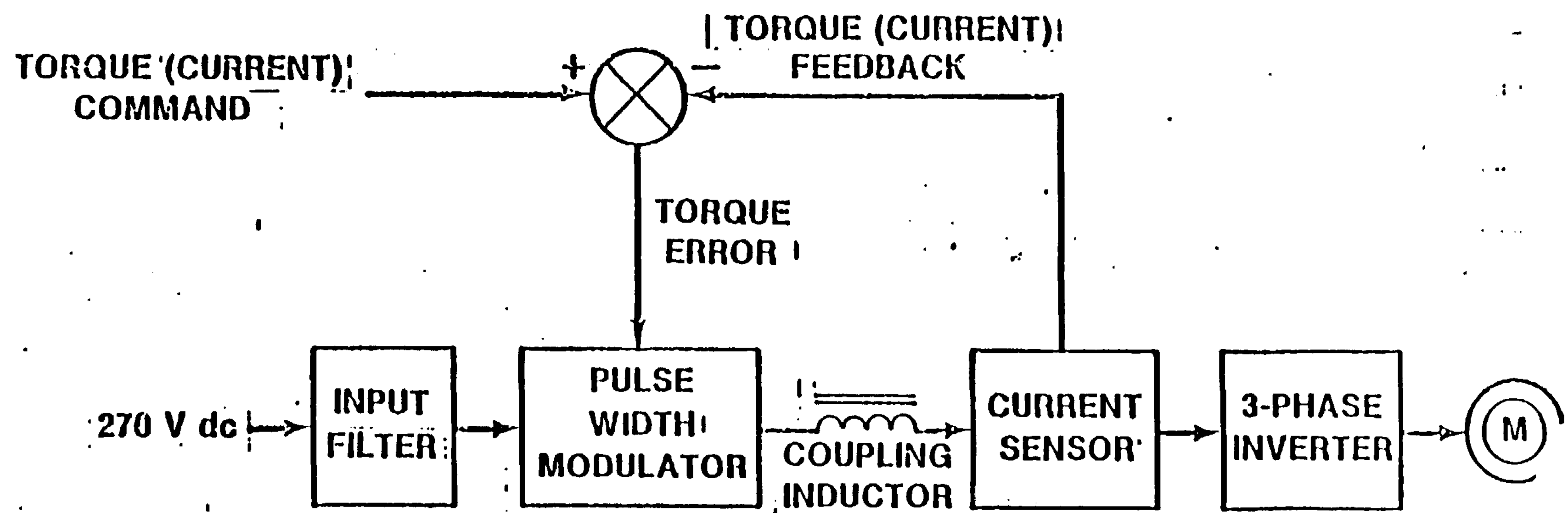
NASA-S-78-11282

EM ACTUATOR BLOCK DIAGRAM



25

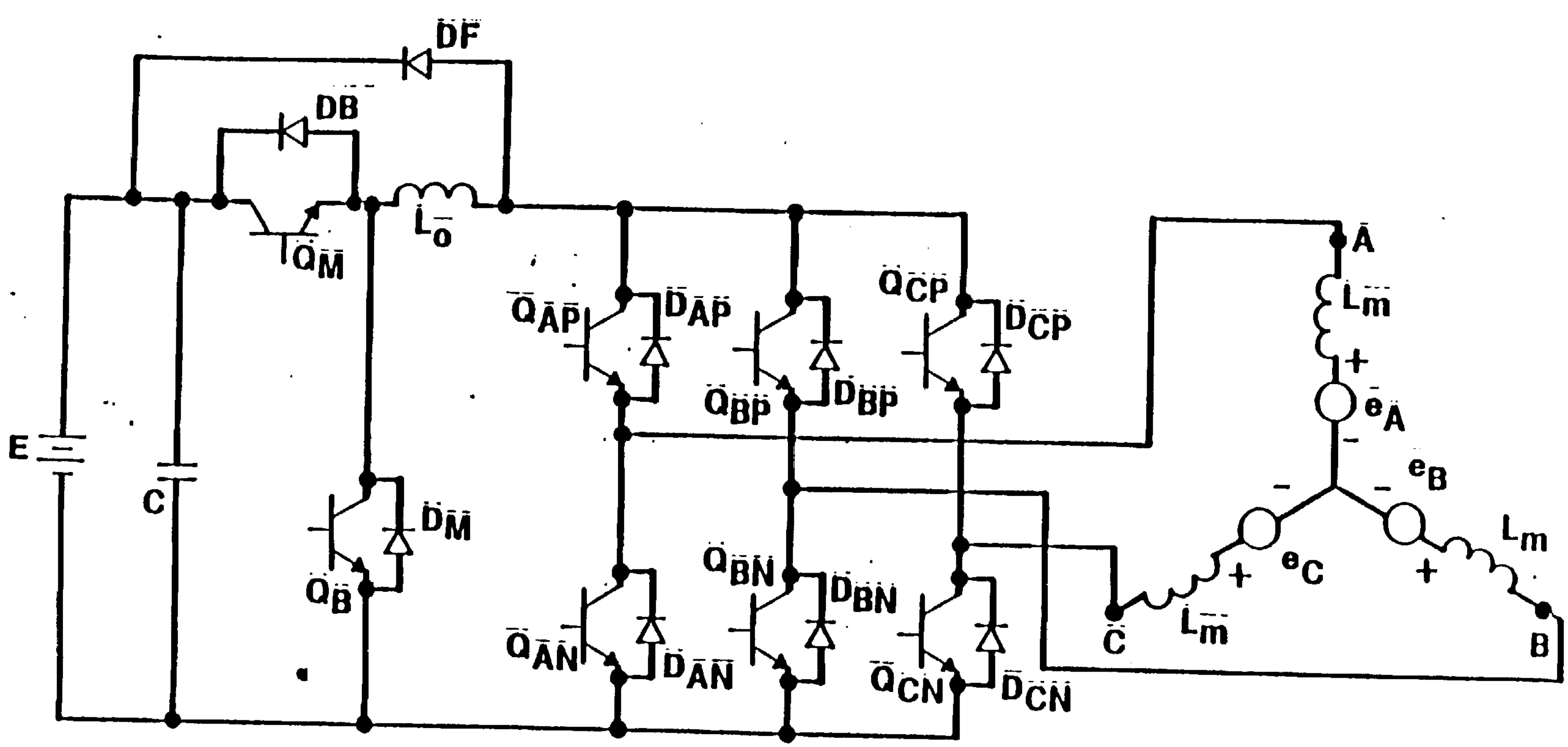
MOTOR DRIVE UNIT	NAVIGATION& CONTROL BRANCH	
	J. T. EDGE	3-23-79



22

NASA-S-78-11284

POWER ELECTRONICS SCHEMATIC



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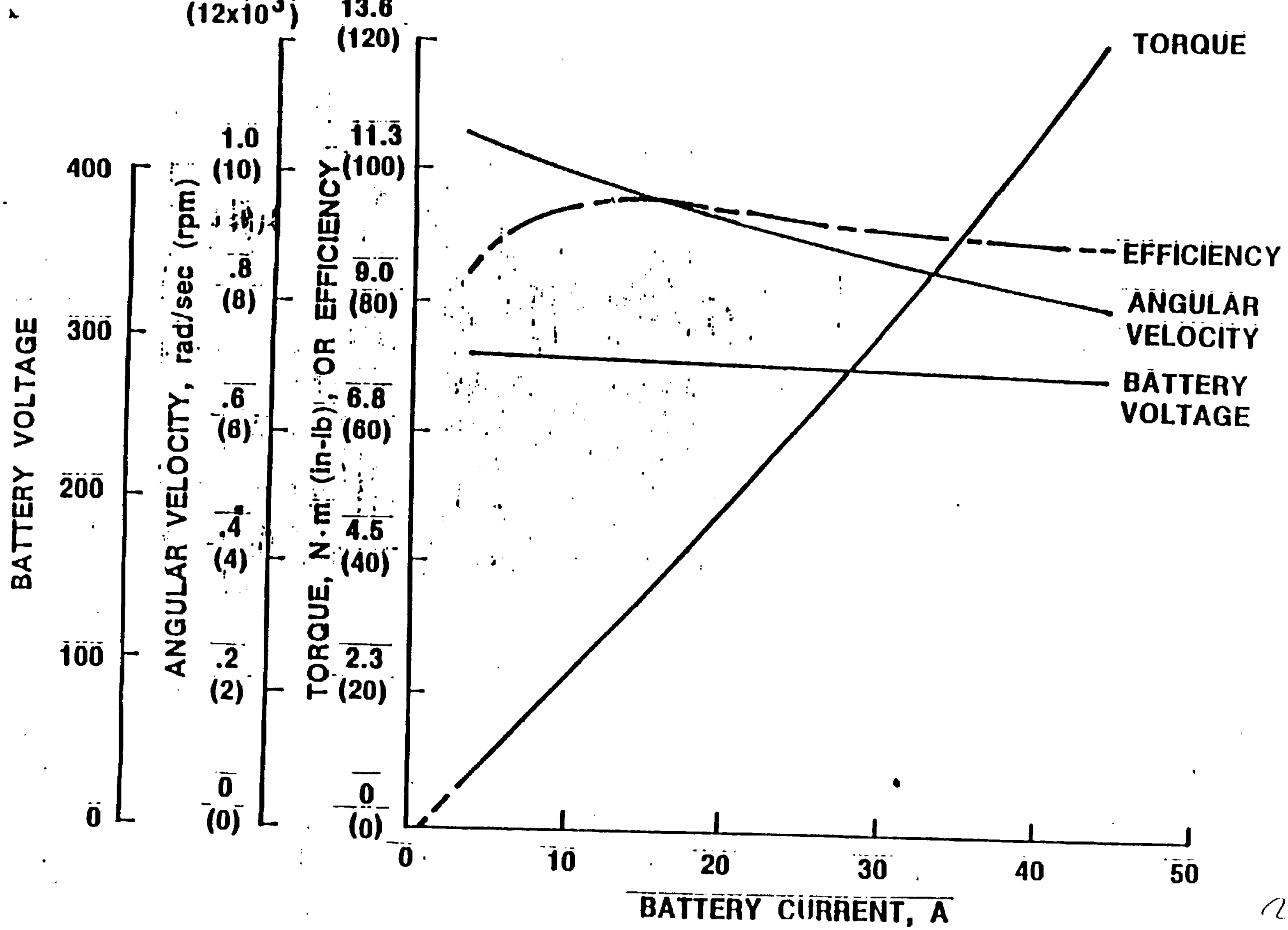
NASA-S-78-11288

MOTOR TEST DATA - MOTORING MODE



24

TABLE 1 - JSC EM ACTUATOR PERFORMANCE REQUIREMENTS (TWO CHANNELS OPERATING)

AVIONICS SYSTEMS DIVISION
W. L. SWINGLE

PARAMETER	REQUIREMENT	MEASURED
THRESHOLD, DEG	0.055	0.02
POSITION NULL, DEG	0.0275	0.02
LINEARITY, DEG	0.55	0.4
ACCURACY, DEG	1.1	0.6
HYSTERESIS, DEG	0.055	± 0.008
VELOCITY, DEG/SEC	20.0	22.7
TORQUE, N·M (IN-LB)	0.056×10^6 (0.495×10^6)	0.056×10^6 (0.495×10^6)*
FREQUENCY RESPONSE		
FREQUENCY, HZ	3	3.5
AMPLITUDE, DEG PEAK-TO-PEAK	0.275	>.275
GAIN, DB	-4	0
PHASE, DEG	-45	-45
STEP RESPONSE		
DISPLACEMENT, % FULL SCALE	5	5
TIME TO 85%, MSEC	145	137**
OVERSHOOT, %	25	8**
SETTLING TIME, MSEC	490	240**

* CALCULATED WITH GEARTRAIN EFFICIENCY OF 77% AND MOTOR TORQUE OF 13.6 N·M (120 IN-LB)

**MEASURED AT 80 IN-LB TORQUE LIMIT, EXTRAPOLATED TO 120 IN-LB TORQUE LIMIT

26
15

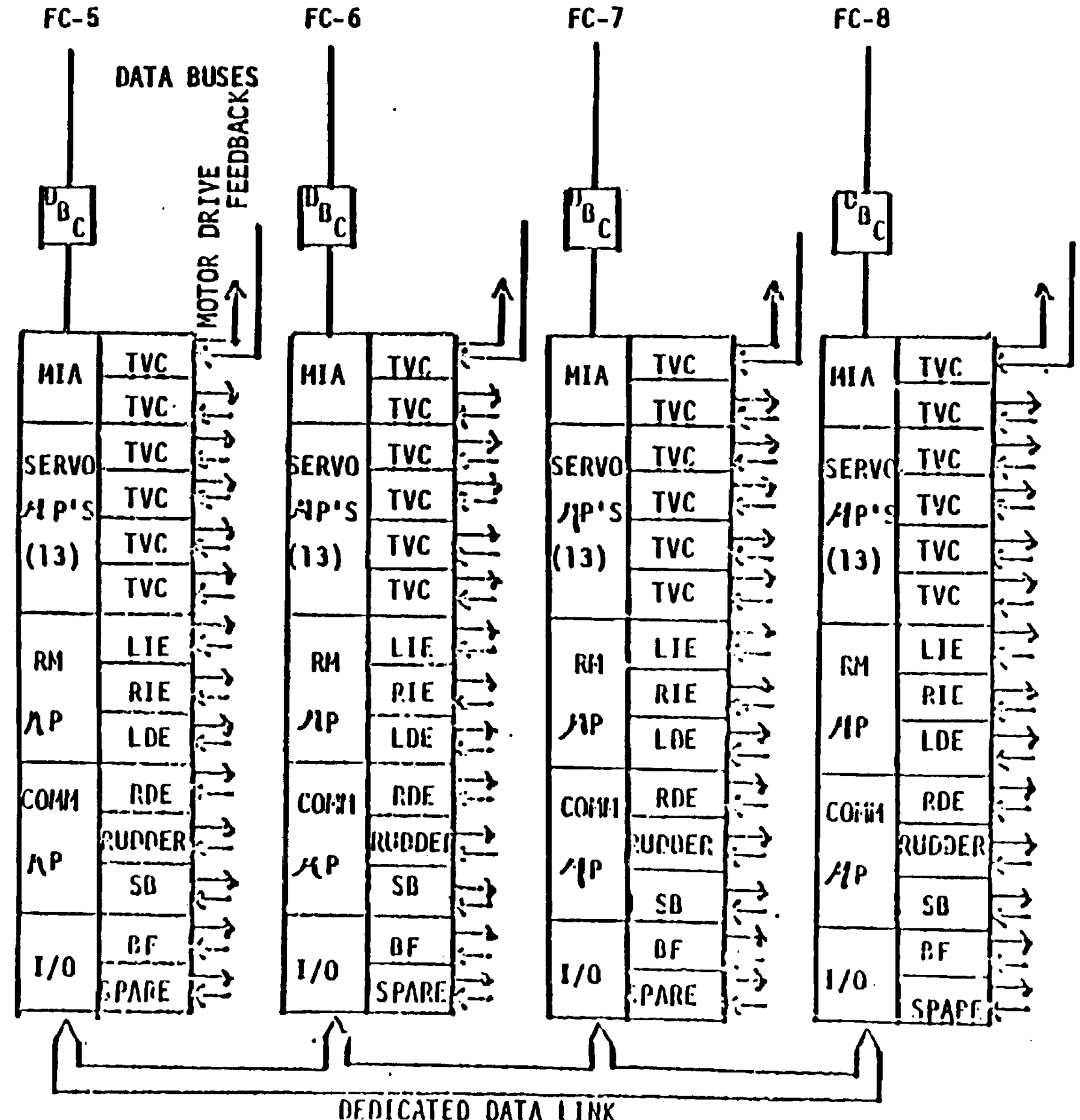
Lyndon B. Johnson Space Center

Engineering and Development Directorate

INTERFACE DIAGRAM FOR ACTUATOR CONTROL UNITS

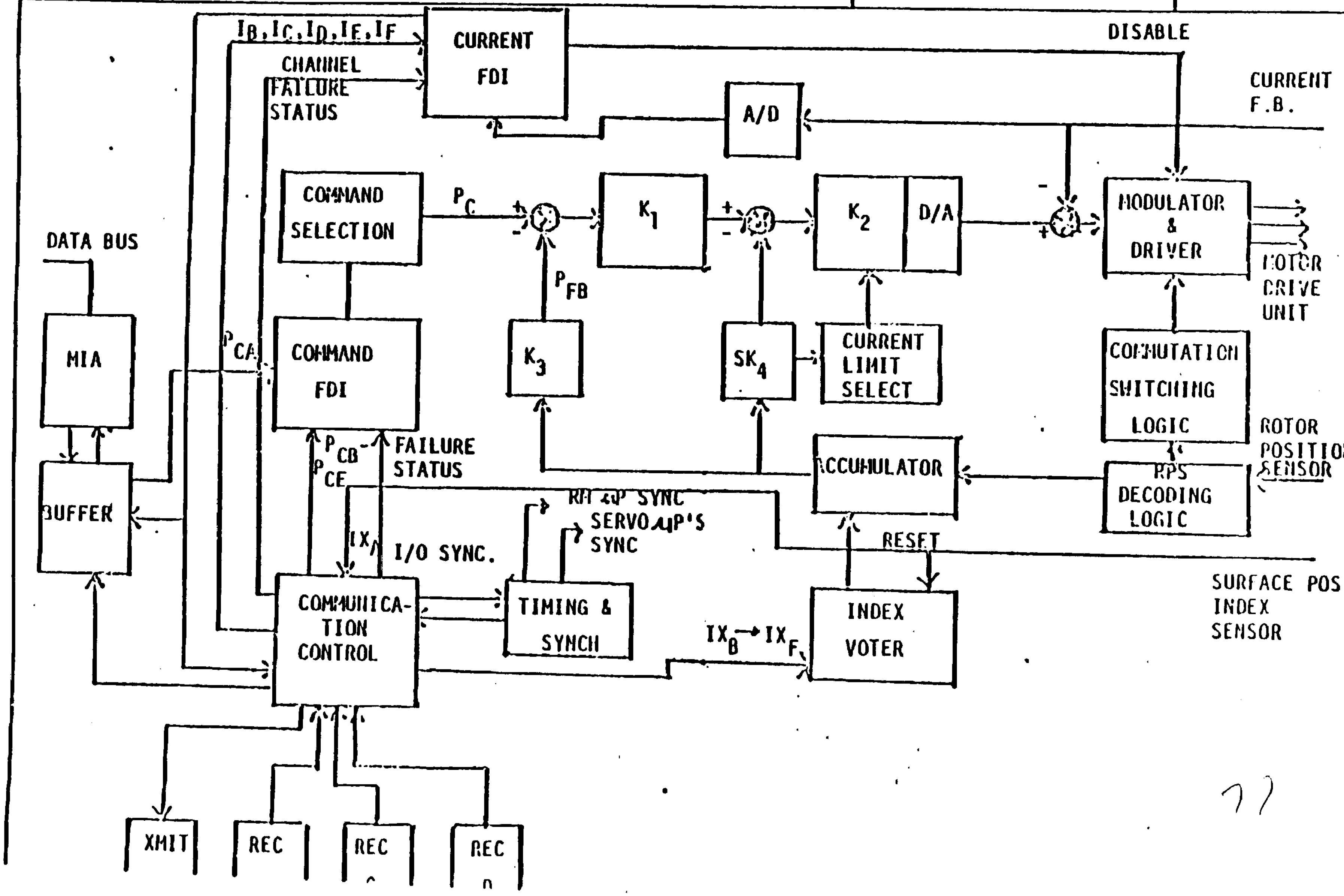
AVIONICS SYSTEMS DIVISION

J. E. YEO



SINGLE CHANNEL ACTUATOR CONTROL UNIT BLOCK DIAGRAM

AVIONICS SYSTEMS DIVISION
W. L. SWINGLE



77

ELECTRONICS DESIGN FEATURES	AVIONICS SYSTEMS DIVISION	
	EH4/J. E. YEO	3-22-79

- EACH CONTROL UNIT HAS IDENTICAL STRUCTURE
- CONTROL UNIT MADE UP OF:
  - ONE MICROPROCESSOR TO HANDLE COMMUNICATIONS
  - ONE MICROPROCESSOR TO HANDLE REDUNDANCY MANAGEMENT
  - ONE MICROPROCESSOR PER CHANNEL FOR SERVO CONTROL
  - DEDICATED CIRCUITRY FOR INTER-BOX COMMUNICATIONS
  - DEDICATED MOTOR CURRENT CONTROL CIRCUITRY FOR EACH CHANNEL
- FOUR UNITS RECEIVE SERVO COMMANDS FOR GPC'S. COMMANDS AND ACTUATOR FEEDBACK SIGNALS ARE CROSS-STRAPPED TO ALL UNITS VIA DEDICATED SERIAL DATA LINES.
- ALLFOUR UNITS INTERFACED TO GPC'S FOR OVERRIDE COMMANDS AND STATUS FEEDBACK
- SERVO MICROPROCESSORS OPERATES WITH 5 MSEC CYCLE TIME
- COMMUNICATIONS MICROPROCESSOR OPERATES WITH 40 MSEC CYCLE SYNC'ED TO GPC COMMAND
- REDUNDANCY MANAGEMENT MICROPROCESSOR OPERATES WITH 40 MSEC MINOR CYCLE AND UP TO 1 SEC MAJOR CYCLE TIME.
- CURRENT FEEDBACK COMPARISON IS USED TO DISABLE MOTOR DRIVE.

- GPC TRANSMITTED RESET AND OVERRIDE COMMANDS WILL BE ACCEPTED
- NO CONTINUOUS SURFACE POSITION OR VELOCITY SENSORS ARE REQUIRED. DIGITAL ROTOR POSITION SENSOR DATA IS ACCUMULATED AND SCALED TO PROVIDE HIGH RESOLUTION SIGNAL. ACCUMULATOR IS RESET BY VOTED SURFACE POSITION INDEX SENSOR. TECHNIQUE MINIMIZES SENSOR ERRORS AS SOURCE OF ACTUATOR FORCE FIGHT, BUT REQUIRES ACTUATOR SLEWING SEQUENCE AT POWER-UP.

DATA FLOW ON ORBITER DATA BUS	AVIONICS SYSTEMS DIVISION	
	EH4/J. E. YEO	3-22-79

GPC TO ACTUATOR CONTROL UNIT

- POSITION COMMAND ON EACH OF 4 BUSES
- RATE LIMIT COMMAND FOR EACH CHANNEL
- OVERRIDE COMMAND TO ENABLE ENTIRE CHANNEL THUS DISABLING CURRENT FDI
- RESET COMMAND FOR CURRENT FDI WITHOUT DISABLING CURRENT FDI

ACTUATOR CONTROL UNIT TO GPC

- ACTUATOR POSITION
- ACTUATOR VELOCITY
- REDUNDANCY MANAGEMENT STATUS
  - CHANNEL FAILURE STATUS ("I FAILED" FROM THIS BOX)
  - COMMAND FAILURE STATUS ("I FAILED" FROM THIS BOX)
- MODE STATUS

10

DATA FLOW ON UNI-DIRECTIONAL SERIAL DIGITAL DATA LINKS	AVIONICS SYSTEMS DIVISION	
	EH4/J. E. YEO	3-22-79

- COMMANDED POSITION AS RECEIVED VIA MIA
- SENSOR FEEDBACK DATA FOR EACH ACTUATOR
  - POSITION INITIALIZATION INDEX
  - VELOCITY
  - MOTOR CURRENT
- REDUNDANCY MANAGEMENT STATUS
  - CHANNEL FAILURE STATUS - "I FAILED"
  - COMMAND FAILURE STATUS - "I FAILED"

8

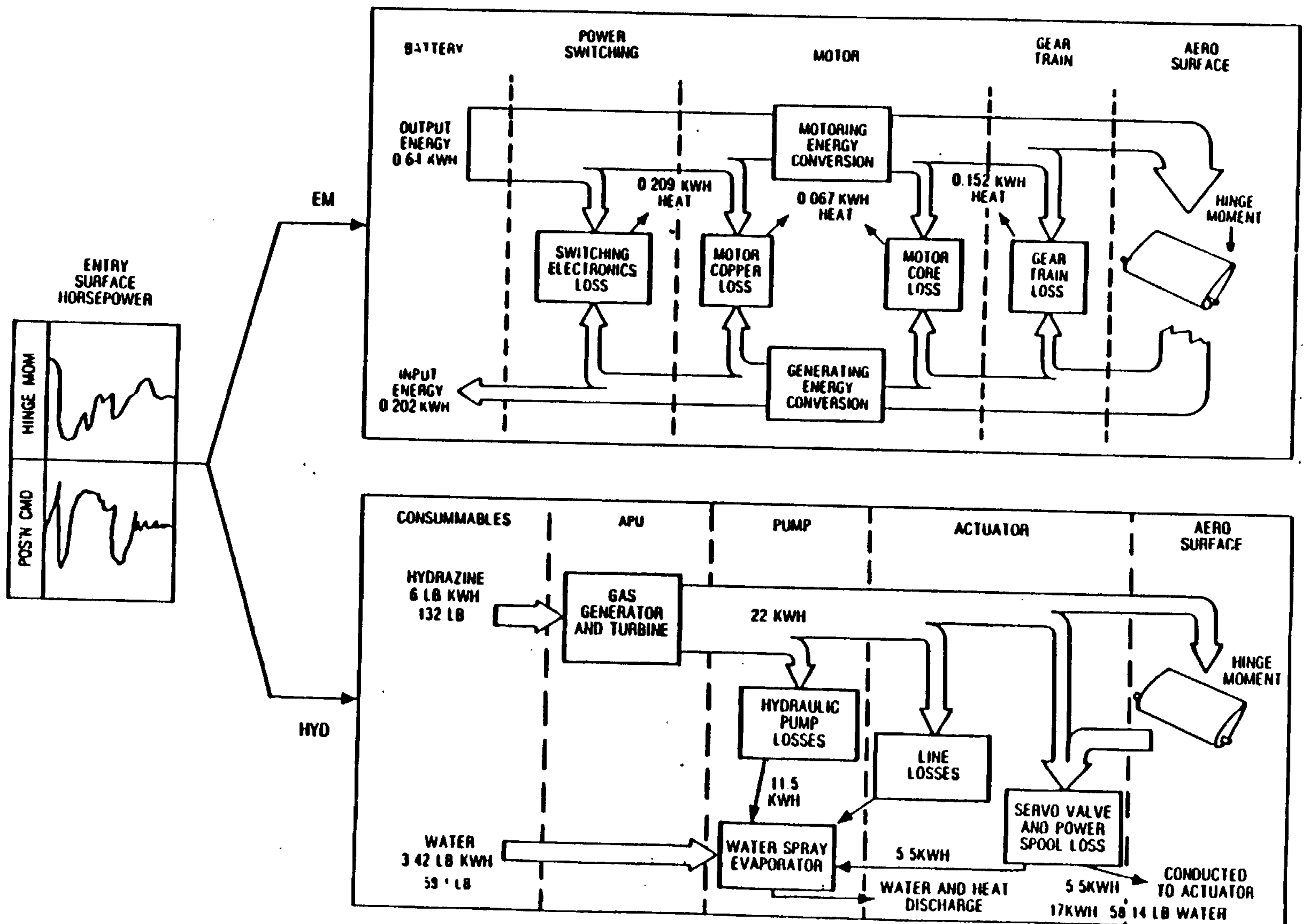
ACTUATOR CONTROL UNIT CHARACTERISTICS	AVIONICS SYSTEMS DIVISION	
	EH4/J. E. YEO	3-22-79

- POWER - 350 WATTS
- WEIGHT - 55 LBS.
- SIZE - 7.625" x 10.125" x 32" (2470.5 IN^3)

NOTES: (1) COLD PLATE COOLING IS REQUIRED.

(2) DESIGN BASED ON CURRENTLY AVAILABLE COMMERCIAL PARTS. ASSUMPTION WAS MADE THAT SIMILAR HI-REL PARTS WOULD BE AVAILABLE WHEN REQUIRED.

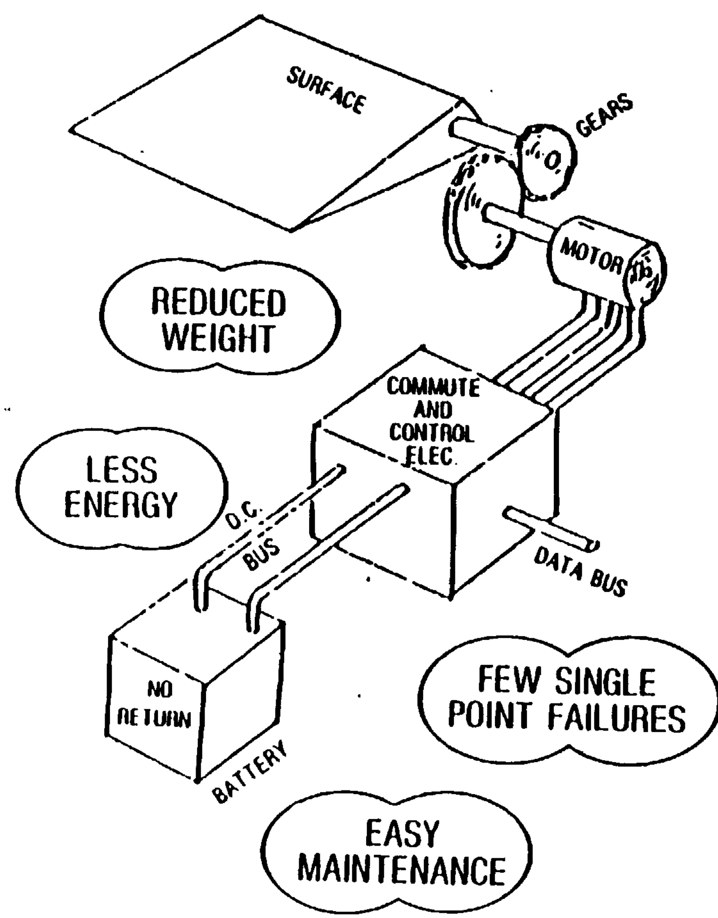
EM VERSUS HYDRAULIC ACTUATION ENERGY FLOW; ENTRY MISSION PHASE



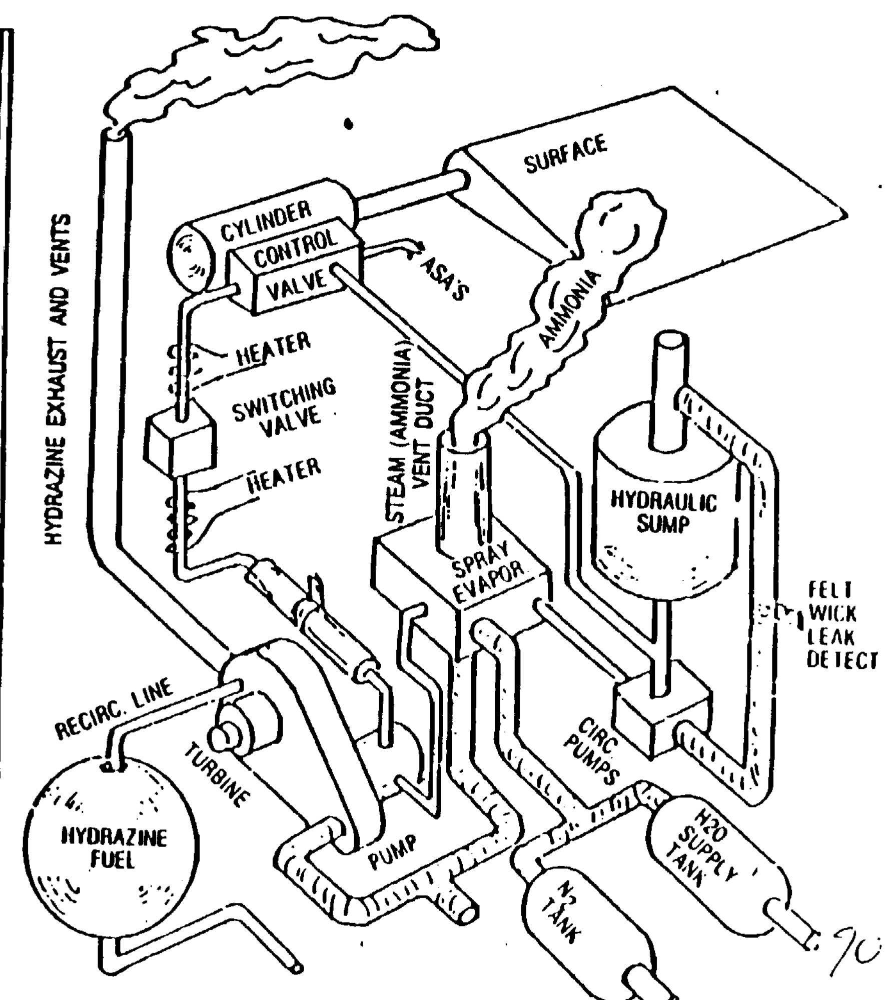
65

OBJECTIVE COMPARISON
EMAs ARE GOOD FOR SHUTTLE

ELECTROMECHANICAL ACTUATION



HYDRAULIC ACTUATION

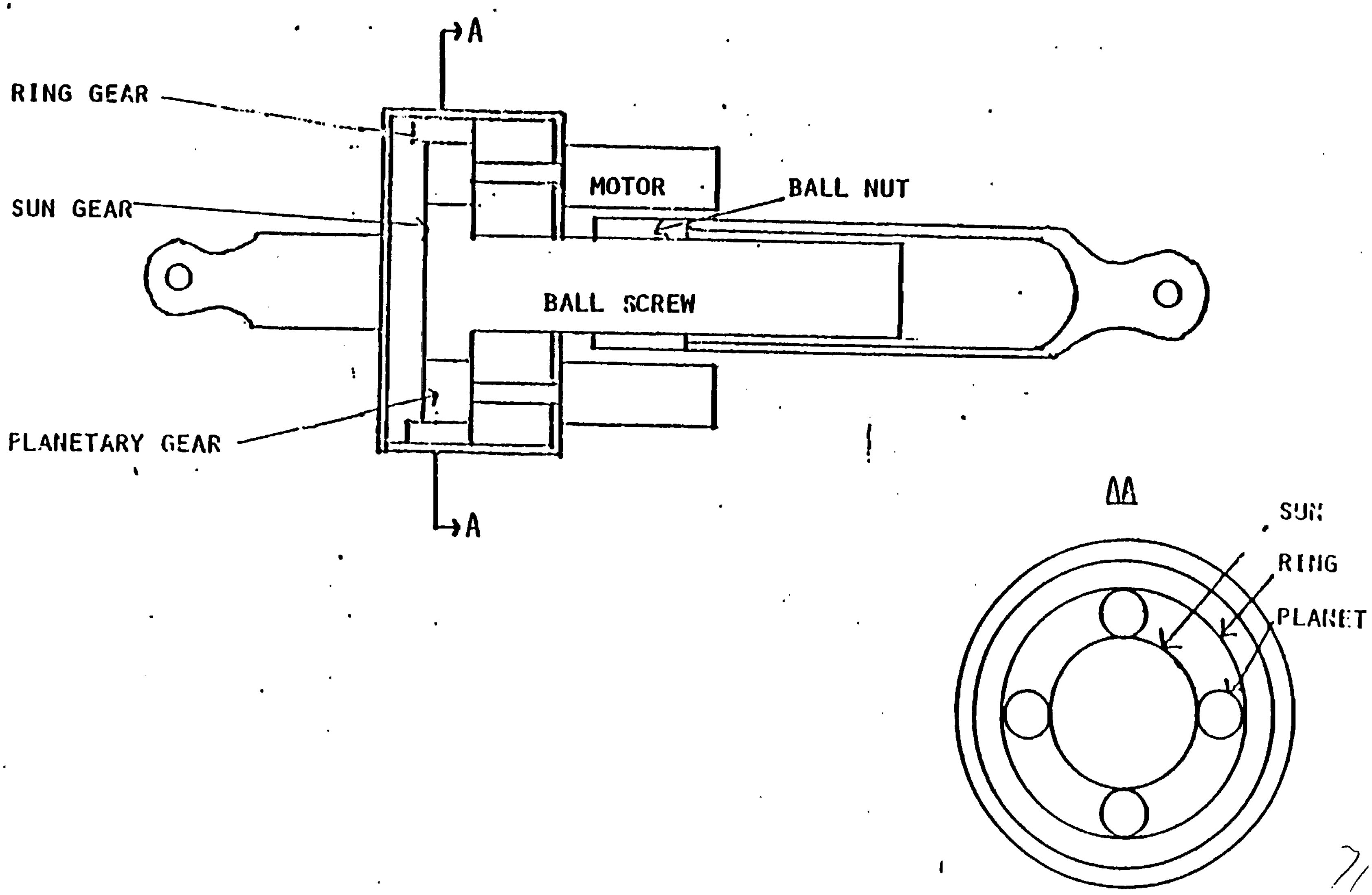


90

LINEAR ACTUATOR CONCEPT

AVIONICS SYSTEMS DIVISION

W. L. SWINGLE

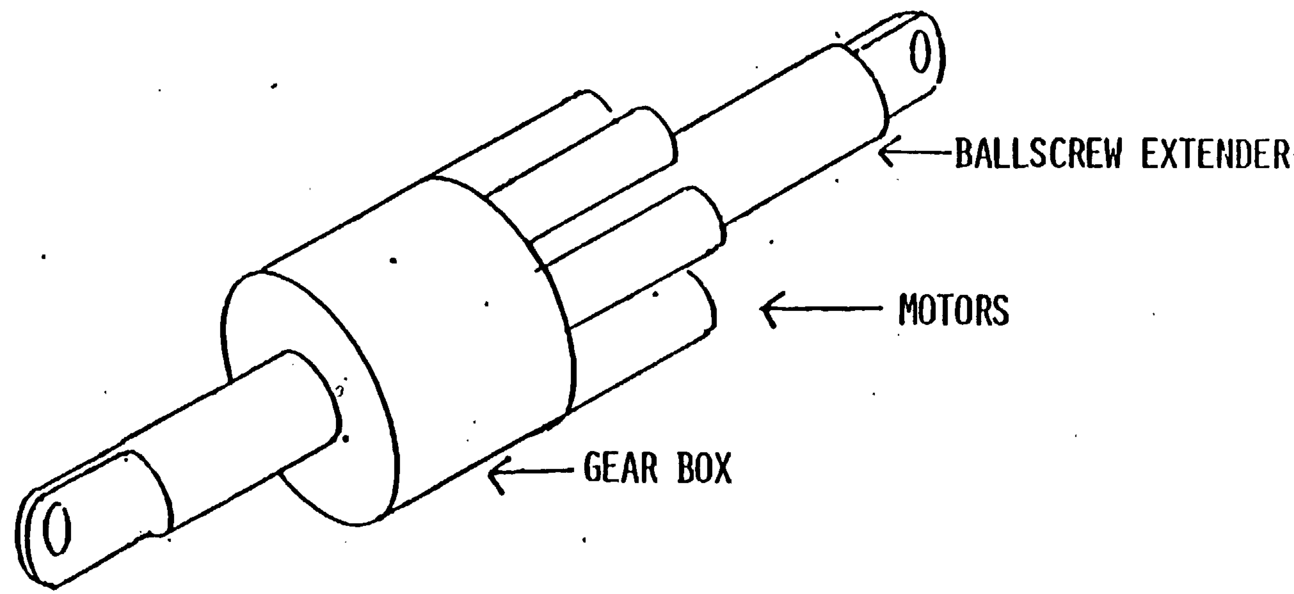


71

ELEVON EM ACTUATOR CONCEPT

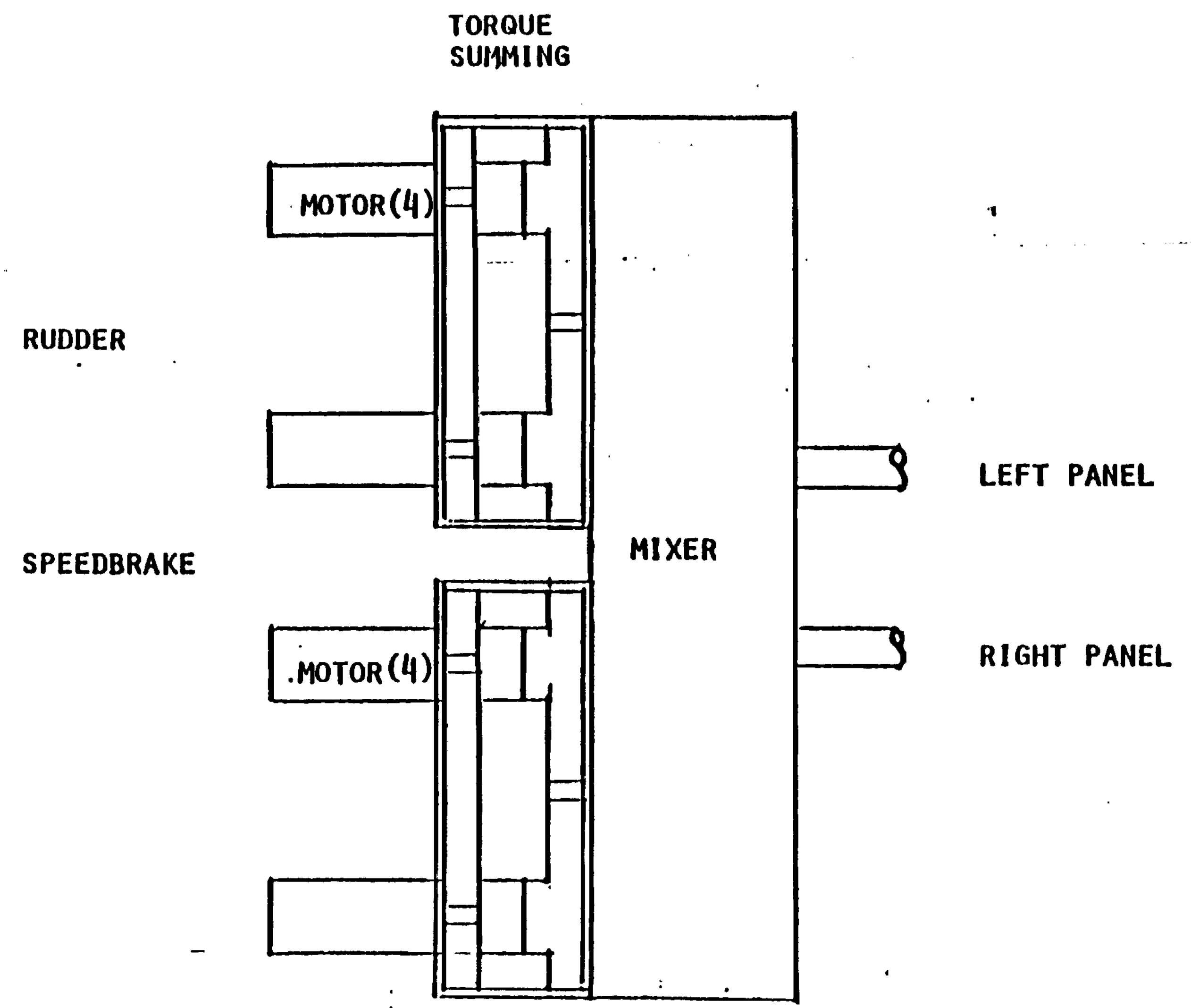
AVIONICS SYSTEMS DIVISION

W. L. SWINGLE



RUDDER/SPEEDBRAKE PDU CONCEPT

AVIONICS SYSTEMS DIVISION
W. L. SWINGLE



ENGINE CONTROL TRADE STUDY

Both engine control candidates are based on the SSMEC engine controller which is a man-rated device that uses class "S" parts and in dual redundant.

Preliminary technical descriptions of the pump-fed and pressure-fed engines have been used to establish comparisons to the SSMEC controller. Input and output signal estimates have been used to predict I/O requirements for estimates of card counts, size, and power. The results have indicated that the pressure-fed engine would require a less complex engine controller.

DDT&E Costs

The input/output requirements of the pressured EC are 67% of the pumped EC. The total card count of the pressured EC is 88% of the pumped EC.

	PU	PR
Score	9	10

Life Cycle Costs

DDT&E, Production, and Operations

	PU	PR
DDT & E	(9)	(10)
Production	(9)	(10)
Operations (I/F)	(7)	(10)
	25	30
Score	8	10

Operational Complexity

Function of the number of interfaces.

	PU	PR
I/O	198	133
Score	7	10

Recovery/Reusability

No difference.

PU	PR
10	10

Size

Weight estimate based on SSMEC percentage and +28 vdc power supplies.

	PU	PR
Weight	180	155
Score	9	10

Power

Power estimate found on SSMEC percentage.

	PU	PR
Power	350	328
Score	9	10

Safety/Reliability

Inverse function of card count.

	PU	PR
Count	43	38
Score	9	10

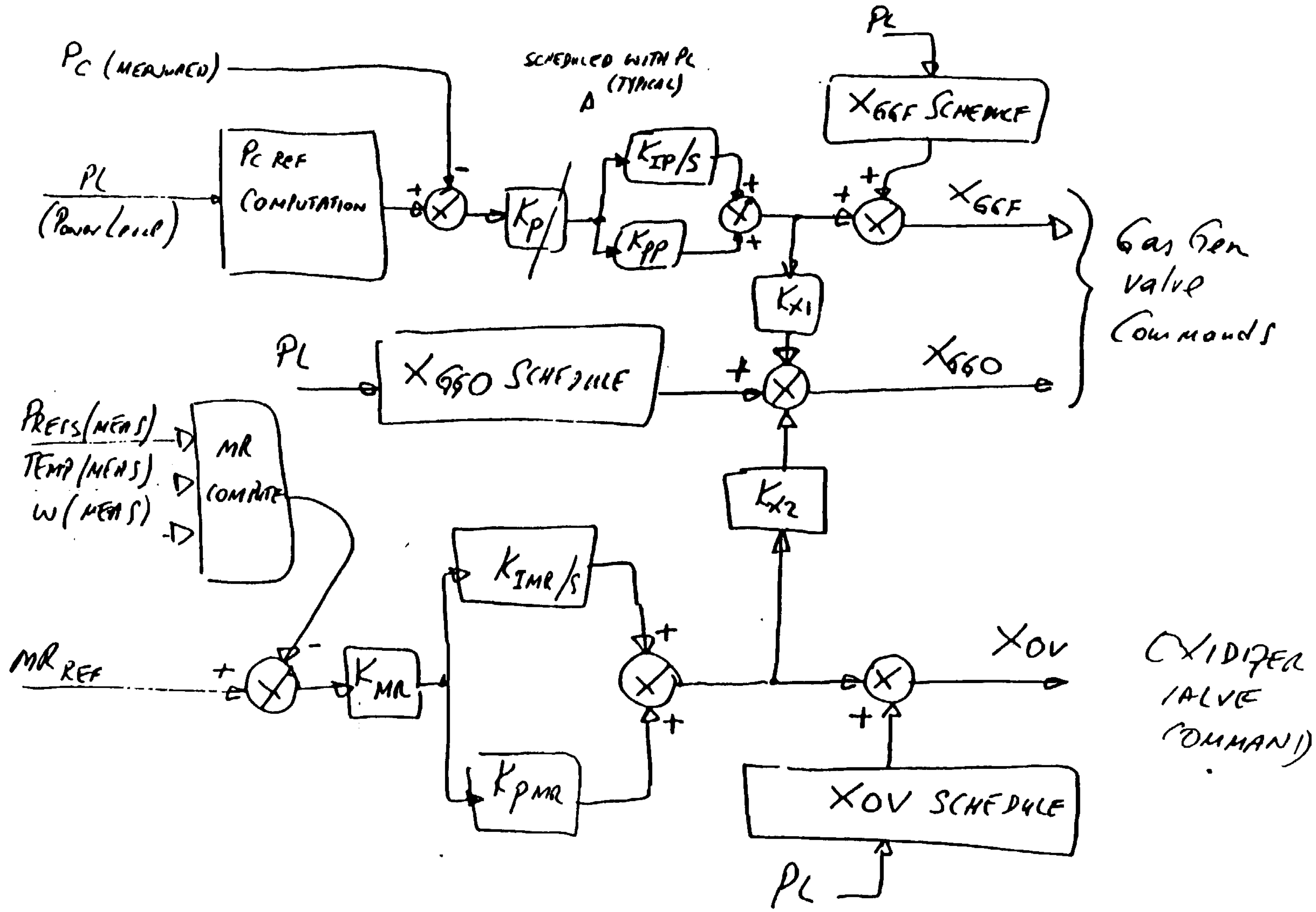
Technical Risk

No difference

	PU	PR
	10	10

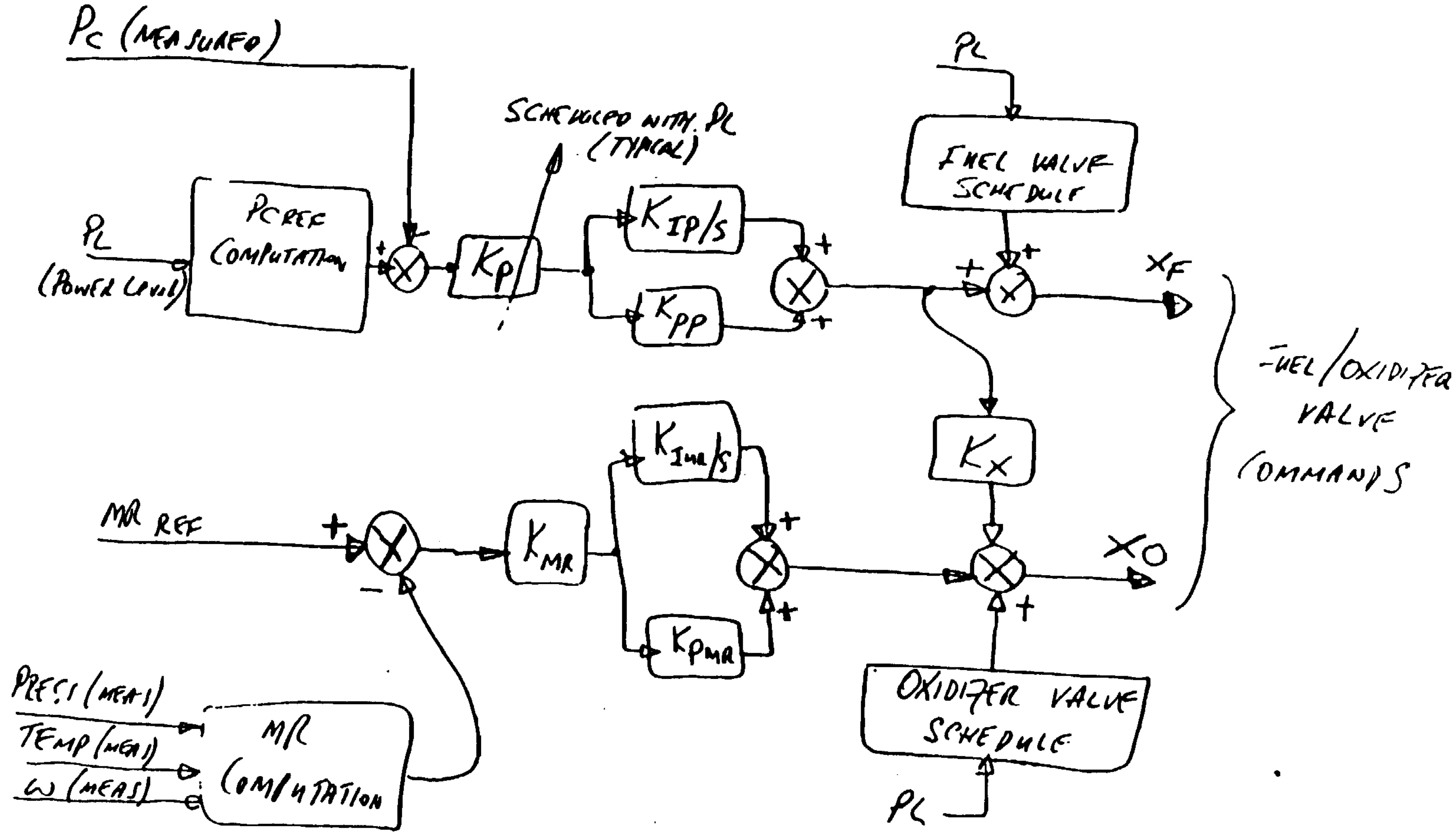
BJM35/s

LRB PUMP FED VALVE CONTROL LAW
ANALYTICAL BLOCK DIAGRAM



R. Matulenko
1-8-88

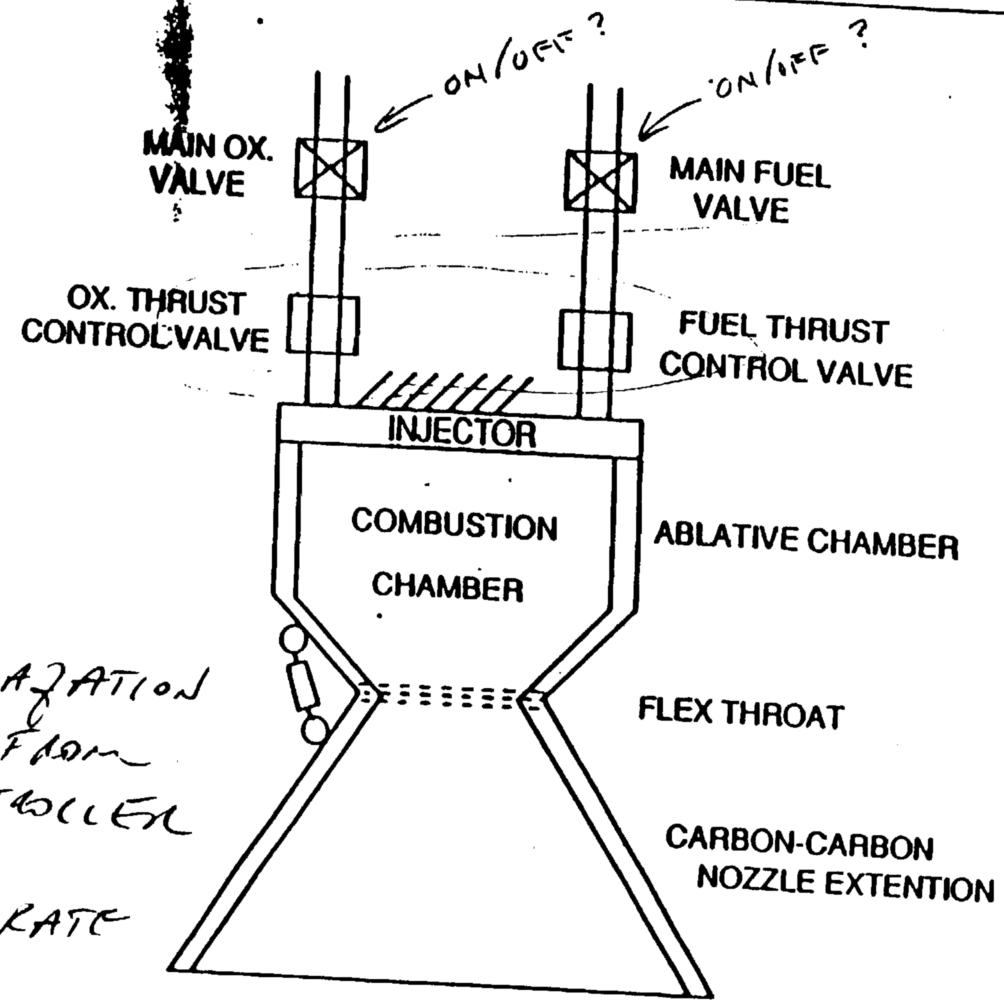
LRB PRESSURE FED VALVE CONTROL LAW ANALYTICAL BLOCK DIAGRAM



R. Matulonko
1-8-88

TechSystems COMPANY

LRB PRESSURE FED ENGINE SCHEMATIC
GIMBALED SYSTEM



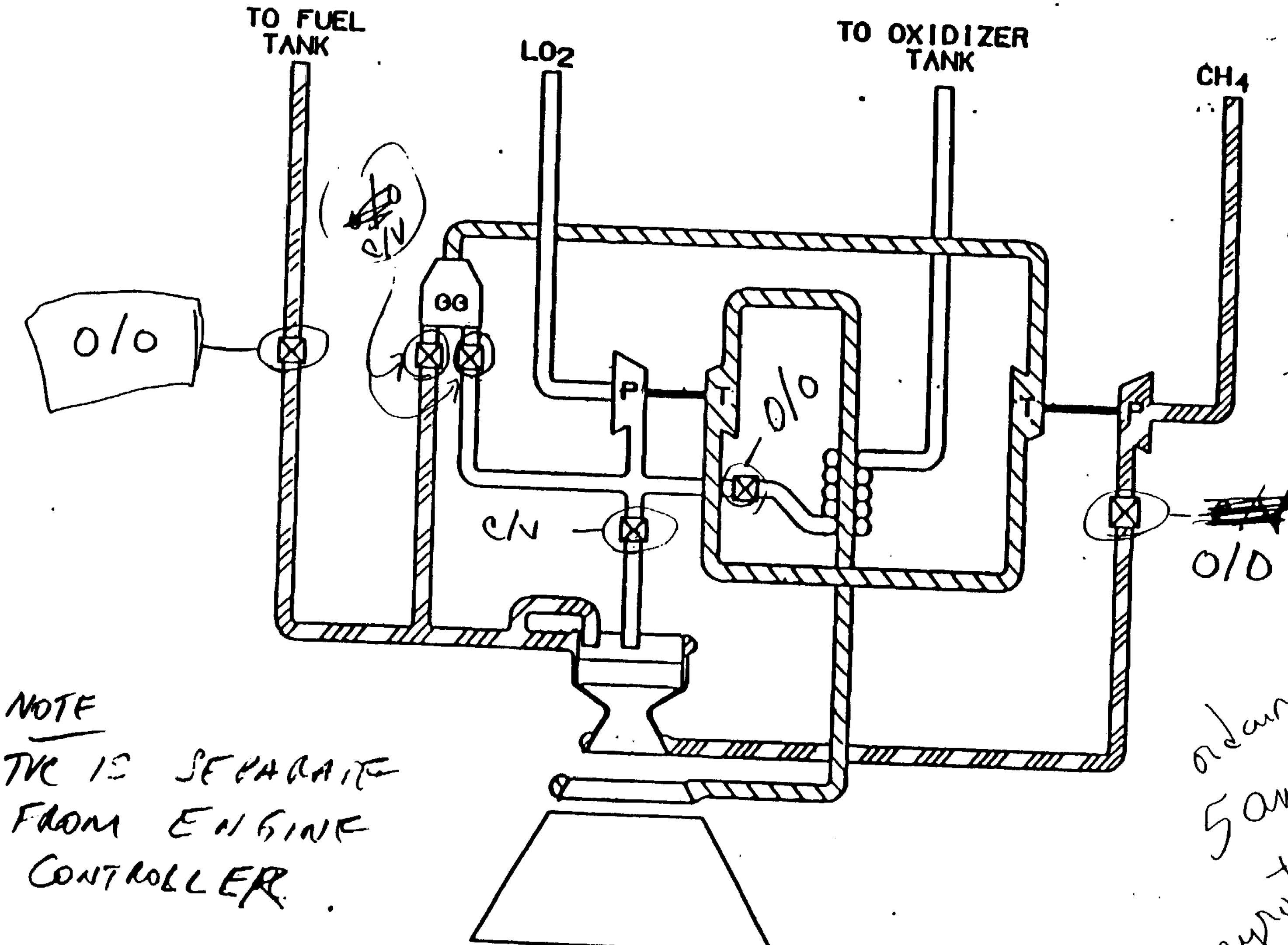
NOTE)

1) TANK PRESSURAZATION IS SEPARATE FROM ENGINE CONTROLLER

2) TVC IS SEPARATE FROM ENGINE CONTROLLER

AEROJET TechSystems COMPANY

Pump Fed Engine Schematic



Solid motor pyro
redundant
one per engine

O/O = On/OFF
C/V = Control Valve

ordnance type
5 amp.
pyrotechnic initiator

NOTE
TVC IS SEPARATE FROM ENGINE CONTROLLER.

-35°F to +160°F
(~~-60~~ to +220°F)

.9998 reliability

Requirement / Function	LR3	
	Pump Fed	Press Fed
Failure criteria as in SSMEC : Fail/OP, Fail/Safe	✓	✓
Two channels as in SSMEC	✓	✓
Closed loop thrust & MR control (~~X~~ 5 valves in SSMEC)	3 valve control	2 valve control
Valve open loop scheduling (~~X~~ 9 valves in SSMEC)	3~~X~~ valve control	2~~X~~ valve control
No of sensors Req. with Redundancy (80 sensors in SSMEC)	75 ~~79~~% of SSMEC	40 ~~44~~% of SSMEC
No of Coils (28 in SSMEC)	~~92~~ ~~86~~ 100 % of SSMEC	~~46~~ ~~50~~ 57 % of SSMEC
~~Controller Temp Control as in SSMEC Block I~~	Not Req'd	not Req'd
Circuit Monitors as in SSMEC (85)	(73) ✓ 86%	(62) ✓ 73%
Circuit Component C/O as in SSMEC	✓	✓
GSE Interface	Similar to SSMEC	Similar to SSMEC
Command / Data Interface	Similar to SSMEC	Similar to SSMEC
Controller Sampling Rate	50 Hz	50 Hz
Closed Loop Bandwidth	2 Hz	2 Hz
Operating Temp Range	-35°C to +72°C	-35°C to +72°C
Reliability	.9998	.9998

Solenoid Count Comparison
SSMEC / LRB

SSMEC

Honeywell

GOVERNMENT AND AERONAUTICAL PRODUCTS DIVISION CODE IDENT NO. 94580

SPECIFICATION NO. DS 25401-04

TABLE XXII

PNEUMATIC SOLENOID AND SERVOSWITCH VALVE INTERFACES

Coils/Valve (Number)	Function	LRB EC Pump FED	LRB EC PRESS FED
2	HPOP Int. Seal Pressurization	S	NA
2	Emergency Shutdown		
2 — N/A	POGO Precharge Control — N/A	8 ~~NA~~	8 ~~NA~~
2	Fuel System Purge (He)		
2	Bleed Valve Control		
2	Preburner Shutdown Purge	S	NA
1	Spare Pneu. Type 1 Solenoid	NA	NA
2	MOV Failsafe	S	S
2	OPOV Failsafe		
2	FPOV Failsafe	S	NA
2	CCV Failsafe	NA	NA
2	MFV Failsafe		
1	MFV Fail-Operate	S	S
1	MOV Fail-Operate		
1	OPOV Fail-Operate		
1	FPOV Fail-Operate	S	NA
1	CCV Fail-Operate	NA	NA
		22 ~~23~~	12 ~~13~~
	Total	~~[illegible]~~	~~[illegible]~~
	% ; SSMEC	~~[illegible]~~	~~[illegible]~~
		~~82%~~	46%
		22 + 6 = 28	12 + 4 = 16

[illegible]

Pressure Fed add 4 sol.
Pump Fed add 6 sol.

Sensor Requirements: SSMEC/LRB COMPARISON

Honeywell

AVIONICS DIVISION

SPECIFICATION NO. DS25401-04

Part I

TABLE III
SENSOR RANGES AND REDUNDANCY LEVELS

SSMEC Parameter	Redundancy	Sensor Range	LRB EC PUMP FED ≈60 / 75%	LRB EC PRESS FED ≈34 / 40%
Low Pressure Fuel Turbopump			NA	NA
Discharge Pressure (P1)	2	0 to 300 PSIA		
Discharge Temperature (T3)	2	30 to 55R° (R_o=5000 ohms)		
Shaft Speed (N1)	2*	0 to 20,000 RPM		
Fuel Flowrate (Q1)	4	0 to 18,000 GPM		
High Pressure Fuel Turbopump			S	NA
Discharge Pressure (P2)	1	0 to 9500 PSIA		
Shaft Speed (N2)	2	0 to 45,000 RPM		
Turbine Discharge Temperature (T1)	2***	460 to 2760°R (R_o=50 ohms)		
Coolant Liner Pressure (P21)	2	0 to 4500 PSIA		
Fuel Preburner			S	NA
Chamber Pressure (P3)	4	0 to 7000 PSIA		
Low Pressure Oxidizer Turbopump			NA	NA
Discharge Pressure (P4)	2	0 to 600 PSIA		
Shaft Speed (N3)	2*	0 to 6000 RPM		
High Pressure Oxidizer Turbopump			S	NA
Preburner Pump Discharge Temp. (T4)	2	**160 to 210°R (R_o=5000 Ohms)		
Discharge Pressure (P5)	1	0 to 7000 PSIA		
Preburner Pump Discharge Press (P6)	1	0 to 9500 PSIA		
Oxid Tank Pressurant Press (P14)	1	0 to 7000 PSIA		
Sec.Seal Cavity Press (P16)	2	0 to 300 PSIA		
Shaft Speed (N4)	2	0 to 35,000 RPM		
Turbine Discharge Temp (T2)	2	460 to 2760°R (R_o= 50 ohms)		
Main Combustion Chamber				
MCC Pressure (P9)	4	0 to 3500 PSIA	S	S
MCC Fuel Injection Press (P10)	1	0 to 4500 PSIA	S	S
MCC Coolant Temperature (T5)	1	460 to 2760°R (R_o=50 ohms)	S	NA
MCC Coolant Pressure (P11)	1	0 to 7000 PSIA	S	NA
MCC Lox Dome (T9)	1	110 to 610°R (R_o=1380 ohms)	S	S
Hydraulic System Press (P12)	1	0 to 4000 PSIA	S	S
Hydraulic System Temperature				
MFV Hydraulic Temperature (T8)	2	360 to 760°R (R_o=1380 ohms)		
MOV Hydraulic Temperature (T7)	2	360 to 760°R (R_o=1380 ohms)		

*One level of redundancy is used during checkout only.
** For HG1015AD03, HG1015AE02, HG1015AF17 and on, the Sensor Range is 160-210°R
***Redundancy level may be 3 for Thermocouple Interface.

I-128 | REV T

S = SIMILAR TO SSMEC
NA = NOT APPLICABLE

Sensor Requirements (Cont 2)
SSMEC/LRB COMPARISON

SSMEC			LRB EC Pump Fed	LRB EC Press Fed
Honeywell AVIONICS DIVISION — SPECIFICATION NO. DS 25401-04				
TABLE III SENSOR RANGES AND REDUNDANCY LEVELS (Continued)				
Parameter	**Redundancy**	**Sensor Range**		
Pneumatic Control System				
Oxidizer Preburner Shutdown Purge Pressure (P19)	1	0 to 1500 PSIA	S	NA
Fuel System Purge Pressure (P8)	2	0 to 600 PSIA	S	S
High Pressure Oxidizer Turbopump Intermediate Seal Purge (P15)	2	0 to 600 PSIA	S	NA
POGO Precharge Pressure (P18)	2	0 to 1500 PSIA	~~S~~ ~~NA~~ NA	NA ~~NA~~ S
Fuel Preburner Shutdown Purge Pressure (P13)	1	0 to 1500 PSIA	NA	NA
Emergency Shutdown Pressure (P20)	2	0 to 1500 PSIA	S	S
Controller				
Pressure (P17)	2	0 to 50 PSIA	S	S
Temperature - Operating (T6)	2	-320 to +300°F (R_o = 200 ohms)		
Temperature - Non-Operating	1	-200 to +400°F (R_o = 100 ohms)	S	S
Temperature - Temperature Control Electronics	1	-320 to +300°F (R_o = 200 ohms)	NA	NA
Flow Control Valves				
Main Fuel Valve				
Actuator Rotational Travel	-	84°15' ± 30'	S	S
Actuator RVDT Sensitivity	2	0.0534 volts p-p/deg nominal		
Main Oxidizer Valve				
Actuator Rotational Travel	-	84°15' ± 30'	S	S
Actuator RVDT Sensitivity	2	0.0534 volts p-p/deg nominal		
Oxidizer Preburner Oxidizer Valve				
Actuator Rotational Travel	-	80° (+0, -30')	S	NA
Actuator RVDT Sensitivity	2	0.0563 volts p-p/deg nominal		
Fuel Preburner Oxidizer Valve				
Actuator Rotational Travel	-	80° (+0, -30')	S	NA
Actuator RVDT Sensitivity	2	0.0563 volts p-p/deg nominal		

S = SIMILAR TO SSMEC
NA = NOT APPLICABLE

Sensor Requirements (Cont 3)
SSMEC/LRB COMPARISON

SSMEC			LRB EC PUMP FED	LRB EC PRESS FED
Honeywell AVIONICS DIVISION — SPECIFICATION NO. DS 25401-04 — TABLE III SENSOR RANGES AND REDUNDANCY LEVELS (Continued)				
<u>Parameter</u>	<u>Redundancy</u>	<u>Sensor Range</u>		
Chamber Coolant Valve				
Actuator Rotational Travel	-	80° (+0, -30°)	NA	NA
Actuator RVDT Sensitivity	2	0.0563 volts p-p/deg nominal		
Recirculation/Isolation Valve				
Stroke	-	0 to 0.125 ± .001 inch	~~S~~ NA	~~S~~ NA
LVDT Sensitivity	1	Proportional to square root of distance from sensitive face		
Fuel Bleed Valve				
Stroke	-	0 to 0.235 ± .002 in.	S	S
LVDT Sensitivity	1	Proportional to square root of distance from sensitive face		
Oxidizer Bleed Valve				
Stroke	-	0 to 0.235 ± .002 in.	S	S
LVDT Sensitivity	1	Proportional to square root of distance from sensitive face		
Anti-flood Valve				
Stroke	-	0 to 0.136 ± .002 inch	S	S
LVDT Sensitivity	2	Proportional to square root of distance from sensitive face		
Spare Temperature Bridge Ranges			S	S
LH2/LOX (TS3)	1	30 to 55°R (R_e = 5000 ohms)		
LH2/LOX (TS2)	1	37 to 1160°R (R_e = 1380 ohms)		
Hot Gas (T1A3)	1	460 to 2760°R (R_e = 50 ohms)		

* T1A3 is a spare Temperature Bridge when not used as third redundant channel for HPFT Turbine Discharge Temperature Thermocouple Interface.

S = SIMILAR TO SSMEC
NA = NOT APPLICABLE

Interface Comparison

Interface	Blk II	LRB-Pump	LRB-Pressure
I. Temp. Sensors	26	17 (57%)	9 (30%)
Spares	4		
II. Pressure Sensors	32	24 (67%)	12 (33%)
Spares	4		
III. Flow Sensors	4	4 (100%)	4 (100%)
Spares	0		
IV. Speed Sensors	4	4 (67%)	0
Spares	2		
V. Position Sensors			
a) actuators	10	6 (50%)	4 (33%)
" spares	2		
b) solenoid	5	7 (47%)	9 (60%)
" Spares	10		
VI. Vibration Sensors	6	6 (100%)	0
" Spares	0		
VII Spark Igniters			
a) Command	6	2 (33%)	2 (33%)
b) Monitor	6	2 (33%)	2 (33%)
VIII On/Off Coils			
a) Pneu. Sol. Type 1	6	9 (70%)	6 (46%)
" " " Spare	7		
b) Pneu Sol Type 2	6	9 (70%)	6 (46%)
" " " Spare	7		
c) Servoswitches	15	9 (50%)	6 (33%)
" Spare	3		
— Servovalves	10	6 (50%)	4 (33%)
" Spare	2		
	177	105 (59%)	65 (37%)

BIT I/F Comparison

Interface (BIT)	BLK II	LRB-Pump	LRB-Pressure
	[illegible]	68	62
		78%	71%
Group 1			
SL1 / SL2	2	2	2
S/V Act	12	6	4
POGO R/V	1	0	0
Group 2			
FRVA / FRVB	2	2	2
OX / Fuel BLD	2	2	2
Anti-Flood	2	2	2
Group 3			
Input Power	2	2	2
Battery Input	4	4	4
Group 4			
CCP A/B	2	2	2
S/V DAC	12	6	4
AC+5	2	2	2
Group 5			
PSE Voltages	14	14	14
Group 6			
PSE Voltages	14	14	14
Group 7			
S/V Current	12	6	4
PSE Voltages	4	4	4

Hardware Reduction from SSMEC BLK II

Pump-Fed LRB

Board	OverHead	Reduction	Total
IE1 A/B	20%	80% × 57%	(1.32) 66%
IE 2 A/B	30%	70% × 67%	(1.54) 77%
IE3 A/B	33%	76% × 78%	(1.84) 92%
IE4 A/B	50%	50% × 67%	(1.68) 84%
IE5 A/B	100%		(2.0) 100%
IE6 A	0%	100% × 67%	(1.34) 67%
OE1 A/B	80%	20% × 50%	(1.8) 90%
OE2 A/B	0%	100% × 48%	(.96) 48%
OE3 A/B	20%	80% × 48%	(1.16) 58%
OE4/5 A/B	5%	95% × 48%	(2.09) 51%
OE6 A/B	33%	67% × 33%	(1.1) 55%
OE7 A/B	0%	100% × 48%	(.96) 48%
BLK II 25 cards (IE/OE)			17.7 cards

Reduction = 25 - 18 = 7 cards

Hardware Reduction from SSMEC BLK II

Pressure-Fed LRB

Board	Overhead	Reduction	Total
IE1 A/B	20%	80% × 30%	(.88) 44%
IE2 A/B	30%	70% × 33%	(1.06) 53%
IE3 A/B	33%	76% × 71%	(1.08) 54%
IE4 A/B	50%	50% × 0%	(1.0) 50%
IE5 A/B	100%	0% ×	(2.0) 100%
IE6 A	0%	100% × 0%	(0.0) 0%
OE1 A/B	80%	20% × 33%	(1.74) 87%
OE2 A/B	0%	100% × 48%	(.96) 48%
OE3 A/B	20%	80% × 48%	(1.16) 58%
OE4/5 A/B	5%	95% × 48%	(1.02) 51%
OE6	33%	76% × 33%	(1.16) 58%
OE7	0%	100% × 48%	(.96) 48%

Blk II 25 cards (IE/OE) 13.0 cards

Reduction = 25 - 13 = 12 cards

LRB Controller Power Estimates (Watts)

I. Pump Fed Engine Controller

Ch. A Typical: 174.8 (202.6) ; Ch. A Max : 297.4 (350.5)

Ch. B Typical: 175.1 (199.3) ; Ch. B Max : 298.6 (341.5)

Total Typical: 349.9 (401.9) ; Total Max: 596.0 (692.0)

II. Pressure Fed Engine Controller

Ch. A Typical: 161.5 (202.6) ; Ch. A Max : 275.8 (350.5)

Ch. B Typical: 166.5 (199.3) ; Ch. B Max : 284.2 (341.2)

Total Typical: 328.0 (401.9) ; Total Max: 560.1 (692.0)

Notes:

1. Blk II Controller power numbers are in parenthesis.
2. Power estimates were calculated as a percentage of the Blk II Controller power dissipations based on the percent hardware reduction estimated for the pump fed and pressure fed configurations.

Pump-Fed LRB

Typical Power
Blk II

TABLE 2.0-1
CHANNEL A POWER DISSIPATIONS

		TYPICAL POWER (WATTS)		MAXIMUM POWER (WATTS)	
	DCU SCP-P	10.63		15.47	
	DCU MEM 1	3.37		5.34	
	DCU MEM 2	3.37		5.34	
	DCU MEM 3	3.37		5.34	
	DCU MEM 4	3.37		5.34	
	CIE 1	4.85		8.77	
	CIE 2	4.47		7.44	
	CIE 3	4.19		7.90	
	CIE 4	4.64		8.79	
	CIE 4 (CHANNEL C)	NONE IN CHANNEL A			
	CIE 5	4.40		7.98	
	CIE 6	5.46		10.41	
66%	IE 1	2.02	1.33	2.82	1.86
77%	IE 2	3.37	2.59	5.47	4.21
92%	IE 3	2.71	2.49	5.00	4.60
84%	IE 4	5.03	4.23	9.07	7.62
100%	IE 5	4.42	4.42	7.82	7.82
67%	IE 6 (VSPE)	3.86	2.59	5.47	3.67
	VM 1	.63		1.13	
90%	OE 1	6.68	6.01	10.91	9.92
46%	OE 2	1.77	0.85	9.93	4.77
58%	OE 3	4.39	2.55	6.37	3.70
51%	OE 4/5	2.72	1.39	4.15	2.17
51%	OE 4/5	2.72	1.39	4.15	2.17
55%	OE 6	5.32	2.93	7.11	3.91
48%	OE 7	3.03	1.45	9.52	4.57
		100.79	(86.97)	177.04	(150.24)
	PS A1	38.3		76.8	
	PS A2	16.12		22.12	
	PS A3	16.45		22.98	
	PS A4	3.77		5.60	
	PS A5	8.91		15.39	
	PS A6	5.16		8.23	
	PS A7	4.42		8.26	
	PS A8	6.33		11.34	
	PS A9	1.32		1.47	
	PS A10	.98		1.24	
	TOTAL A	101.76 (87.81)	202.6 (174.78)	173.43 (147.18)	350.5 (297.42)

$$\text{PSE Total}_{TYP} = 101.76 \times \frac{86.97}{100.79} = 87.81$$

$$\text{PSE Total}_{MAX} = 173.43 \times \frac{150.24}{177.04} = 147.18$$

Pump-Fed LRB

Typical Power
Blk II

TABLE 2.0-2
CHANNEL B POWER DISSIPATIONS

		TYPICAL POWER (WATTS)		MAXIMUM POWER (WATTS)	
	DCU SCP-P	10.63		15.47	
	DCU MEM 1	3.37		5.34	
	DCU MEM 2	3.37		5.34	
	DCU MEM 3	3.37		5.34	
	DCU MEM 4	3.37		5.34	
	CIE 1	4.85		8.77	
	CIE 2	4.47		7.44	
	CIE 3	4.19		7.90	
	CIE 4	4.64		8.79	
	CIE 4 (CHANNEL C)	2.45		5.13	
	CIE 5	4.40		7.98	
	CIE 6	5.46		10.41	
66%	IE 1	2.02	1.33	2.82	1.86
77%	IE 2	3.37	2.59	5.47	4.21
92%	IE 3	2.71	2.49	5.00	4.60
84%	IE 4	5.03	4.23	9.07	7.62
100%	IE 5	4.42	4.42	7.82	7.82
61%	IE 6 (VSPE)	NONE IN CHANNEL B			
	VM 1	.63		1.13	
90%	OE 1	6.68	6.01	10.91	9.92
48%	OE 2	1.65	0.85	7.93	4.77
58%	OE 3	4.39	2.56	6.37	3.70
51%	OE 4/5	2.72	1.39	4.15	2.17
51%	OE 4/5	2.72	1.39	4.15	2.17
55%	OE 6	5.32	2.93	7.11	3.91
48%	OE 7	2.66	1.28	6.93	3.33
48		98.89	(86.66)	172.11	(150.46)
50					
	PS A11	36.9		72.8	
	PS A12	16.12		22.12	
	PS A13	16.45		22.98	
	PS A14	3.77		5.60	
	PS A15	8.91		15.39	
	PS A16	5.16		8.23	
	PS A17	4.42		8.26	
	PS A18	6.33		11.34	
	PS A19	1.32		1.47	
	PS A20	0.98		1.24	
	TOTAL B	100.36 (88.39)	199.3 (175.05)	169.43 (148.12)	341.5 (298.58)
	TOTAL A & B		401.9 (349.83)		692.0 (596.0)

PSE $\text{Total}_{TYP} = 100.86 \times \frac{86.66}{98.89} = 88.39$

PSE $\text{Total}_{max} = 169.43 \times \frac{150.46}{172.11} = 148.12$

Pressure Fed LRB

Typical Power
Blk II

TABLE 2.0-1
CHANNEL A POWER DISSIPATIONS

	TYPICAL POWER (WATTS)		MAXIMUM POWER (WATTS)	
DCU SCP-P	10.63		15.47	
DCU MEM 1	3.37		5.34	
DCU MEM 2	3.37		5.34	
DCU MEM 3	3.37		5.34	
DCU MEM 4	3.37		5.34	
CIE 1	4.85		8.77	
CIE 2	4.47		7.44	
CIE 3	4.19		7.90	
CIE 4	4.64		8.79	
CIE 4 (CHANNEL C)	NONE IN CHANNEL A			
CIE 5	4.40		7.98	
CIE 6	5.46		10.41	
44% IE 1	2.02	.89	2.82	1.24
53% IE 2	3.37	1.79	5.47	2.90
54% IE 3	2.71	1.46	5.00	2.70
50% IE 4	5.03	2.52	9.07	4.54
100% IE 5	4.42	4.42	7.82	7.82
0% IE 6 (VSPE)	3.86	0.00	5.47	0.00
VM 1	.63		1.13	
87% OE 1	6.68	5.81	10.91	9.49
48% OE 2	1.77	0.85	9.93	4.77
58% OE 3	4.39	2.54	6.37	3.70
51% OE 4/5	2.72	1.39	4.15	2.12
51% OE 4/5	2.72	1.39	4.15	2.12
58% OE 6	5.32	3.09	7.11	4.12
48% OE 7	3.03	1.45	9.52	4.57
	100.79	(80.35)	177.04	(139.34)
PS A1	38.3		76.8	
PS A2	16.12		22.12	
PS A3	16.45		22.98	
PS A4	3.77		5.60	
PS A5	8.91		15.39	
PS A6	5.16		8.23	
PS A7	4.42		8.26	
PS A8	6.33		11.34	
PS A9	1.32		1.47	
PS A10	.98		1.24	
TOTAL A	101.76	202.6	173.43	350.5
	(81.12)	(161.47)	(136.50)	(275.84)

$$PSE\ Total_{Typ} = 101.76 \times \frac{80.35}{100.79} = 81.12$$

$$PSE\ Total_{max} = 173.43 \times \frac{139.34}{177.04} = 136.50$$

Pressure Fed LRB

Typical Power
Blk II

TABLE 2.0-2
CHANNEL B POWER DISSIPATIONS

	TYPICAL POWER (WATTS)		MAXIMUM POWER (WATTS)	
DCU SCP-P	10.63		15.47	
DCU MEM 1	3.37		5.34	
DCU MEM 2	3.37		5.34	
DCU MEM 3	3.37		5.34	
DCU MEM 4	3.37		5.34	
CIE 1	4.85		8.77	
CIE 2	4.47		7.44	
CIE 3	4.19		7.90	
CIE 4	4.64		8.79	
CIE 4 (CHANNEL C)	2.45		5.13	
CIE 5	4.40		7.98	
CIE 6	5.46		10.41	
44% IE 1	2.02	.89	2.82	1.24
53% IE 2	3.37	1.79	5.47	2.90
54% IE 3	2.71	1.46	5.00	2.70
50% IE 4	5.03	2.52	9.07	4.54
100% IE 5	4.42	4.42	7.82	7.82
IE 6 (VSPE)	NONE IN CHANNEL B			
VM 1	.63		1.13	
87% OE 1	6.68	5.81	10.91	9.49
48% OE 2	1.65	0.85	7.93	4.77
58% OE 3	4.39	2.54	6.37	3.70
51% OE 4/5	2.72	1.39	4.15	2.12
51% OE 4/5	2.72	1.39	4.15	2.12
58% OE 6	5.32	3.09	7.11	4.12
46% OE 7	2.66	1.28	6.93	3.33
	98.89	(82.63)	172.11	(143.23)
PS A11	36.9		72.8	
PS A12	16.12		22.12	
PS A13	16.45		22.98	
PS A14	3.77		5.60	
PS A15	8.91		15.39	
PS A16	5.16		8.23	
PS A17	4.42		8.26	
PS A18	6.33		11.34	
PS A19	1.32		1.47	
PS A20	0.98		1.24	
TOTAL B	100.36 (83.85)	199.3 (166.49)	169.43 (141.00)	341.5 (284.23)
TOTAL A & B		401.9 (327.96)		692.0 (560.07)

DCE Total$_{TYP}$ $= 100.36 \times \frac{82.63}{98.89} = 83.85$

P&E Total$_{max}$ $= 169.43 \times \frac{143.23}{172.11} = 141.00$

LRB Controller Size / Weight Estimates

LARRY: 1/22/89

IF WE DID NOTHING OTHER THAN STRIP OUT THE UNUSED PWA's AND REARRANGE THE GUTS TO CLOSE IN THE VACANT SPACES HERE'S WHAT WE WOULD HAVE;

OPTION 1; - STRIPPING 12 PWA's

ENVELOPE = 16.5 H x 14.5 W x 18.5 L

WEIGHT = 160 LBS *

OPTION 2; - STRIPPING 7 PWA'S

ENVELOPE = 16.5 H x 14.5 W x 20.9 L

WEIGHT = 187 LBS *

BY DOING A MAJOR REDESIGN (FROM GROUND UP), STRIPPING OUT EVERYTHING WE COULD, AND USING THE SAME CIRCUIT IMPLEMENTATION (DIPS / DISCRETES) WE COULD PROBABLY GET ANOTHER 10% OUT OF THESE NUMBERS FOR VOLUME AND I WOULD GUESS 15% FOR WEIGHT.

TO DO ANY BETTER WE WOULD HAVE TO DEVELOP OUR DESIGN AROUND HYBRIDIZATION (WHOLESALE), OR CUSTOM LSIC. THE ONLY THING WE HAVE RIGHT NOW TO IMPLEMENT OUR DESIGNS IN IS DIP'S AND THEY ARE THE WORST THING FOR IMPLEMENTING MINIATURIZATION. AS AN EXAMPLE, WHEN WE COULD GET FLAT PACKS WE COULD PACKAGE

2.5 FLAT PACKS IN THE SAME VOLUME
WE COULD GET A DIP INTO !

BILL MARTIN.

* If +28VDC is used for primary power, an additional 5 to 7 pounds would be eliminated from the power supplies.

Option 1 = pressure fed LRB

Option 2 = pump fed LRB

These estimates are based on removing 12 circuit cards from an SSMEC BLK II Controller for the pressure fed LRB Controller and 7 circuit cards from an SSMEC BLK II Controller for the pump fed LRB Controller.

SSMEC BLK II Envelope: 16.5 × 14.5 × 23.5
Weight : 210 LBS

AVIONICS INTERFACE TRADE STUDY

Existing interfaces should be retained for avionics that are common to the SRB and LRB such as the RGAs, RSS system, and SEP system. It is the new avionics required for liquid engine control and support that present new interface requirements.

The SRB interface for TVC utilizes 72 wires to transport six quad redundant functions. If these analog and discrete signals were encoded into a serial bus, the wiring could be utilized for other functions (including redundant serial buses).

If new serial channels could be added to existing MDMs they would provide the serial buses required to service the new LRB functions. However, the conversion of the flight critical bus data to MDM serial bus data format will involve some transport delay. If the added delay does not exceed 20ms it should not cause a control problem.

If new ports could be added to the flight critical buses (involving IOP software revisions), the transport delay could be avoided by bringing the buses directly to the LRB via isolated taps.

STS Integration Impacts

	MDM	BUS	A/D
Wiring (interfaces)	16ch	4ch	300+
	(8)	(10)	(1)
T. Delay	delay	no	no
	(5)	(10)	(10)
ORB Hardware	4 cards	4 xfmrs	4MDMs,connectors
	(8)	(10)	(2)
ORB Software	GPC sw	GPC + BUS	GPC + BUS
	(10)	(5)	(5)
	31	35	18
	8	10	5

DDT&E Costs

Function of Hardware Mods, Software Mods

	MDM	BUS	A/D
ORB Hardware	4 cards	4 taps	4MDMs,connectors
	(8)	(10)	(2)
Software Mods	(10)	(5)	(5)
total	18	15	10
Score	10	9	7

BJM33/s

Life Cycle Costs

DDT&E, Production, Operations

	MDM card	BUS tap	A&D
DDT & E	(10)	(9)	(7)
Production	card + OIA	OIA	MDM
Score	(5)	(10)	(10)
Operations			
I/F Count	16	4	>300
Score	(8)	(10)	(1)
total	23	29	18
Score	8	10	6

Operational Complexity

Function of number of LRUs and interfaces

	MDM serial	BUS tap	Anal/ Disc
LRUs	4cards	4taps	MDM + connectors
	(8)	(10)	(2)
I/F Count	16	4	300
	(8)	(10)	(1)
total	16	20	3
Score	8	10	2

Technical Risks

- Transport delay in serial MDM channel
- Bus Arch. mod for new taps
- Added Connector I/F

	MDM	BUS	A/D
Transport Delay	5	10	10
Bus Arch	10	5	5
I/F Count	8	10	1
total	23	25	16
Score	10	10	6

Safety/Reliability

Function of component count (and redundancy)

	MDM	BUS	A/D
Count	4 cards	4 taps	MDM + connectors
Score	8	10	2

Subsystem Integration

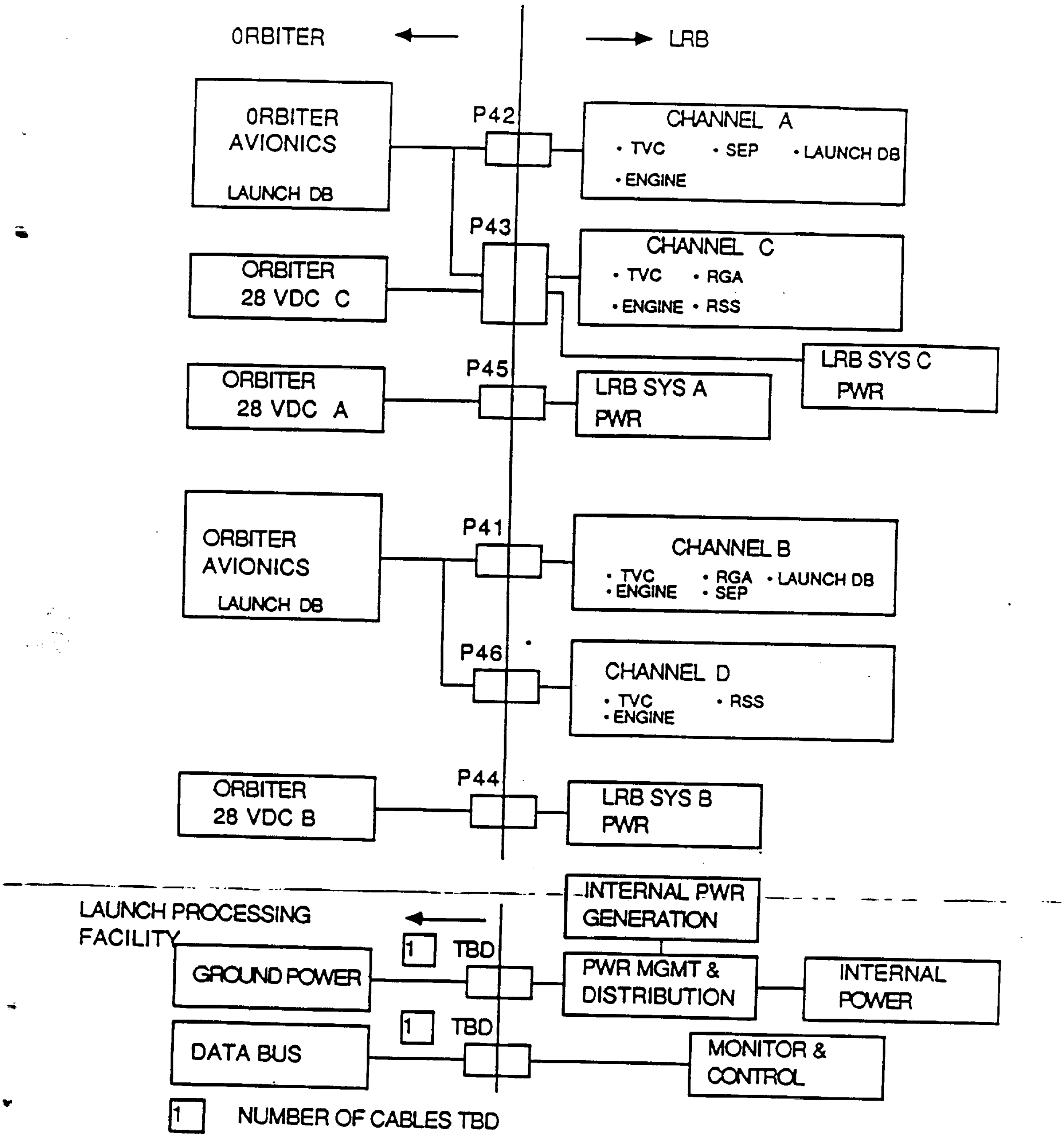
Function of the number of interfaces

MDM	BUS	A/D
16	4	300+
8	10	1

Growth/Evolution

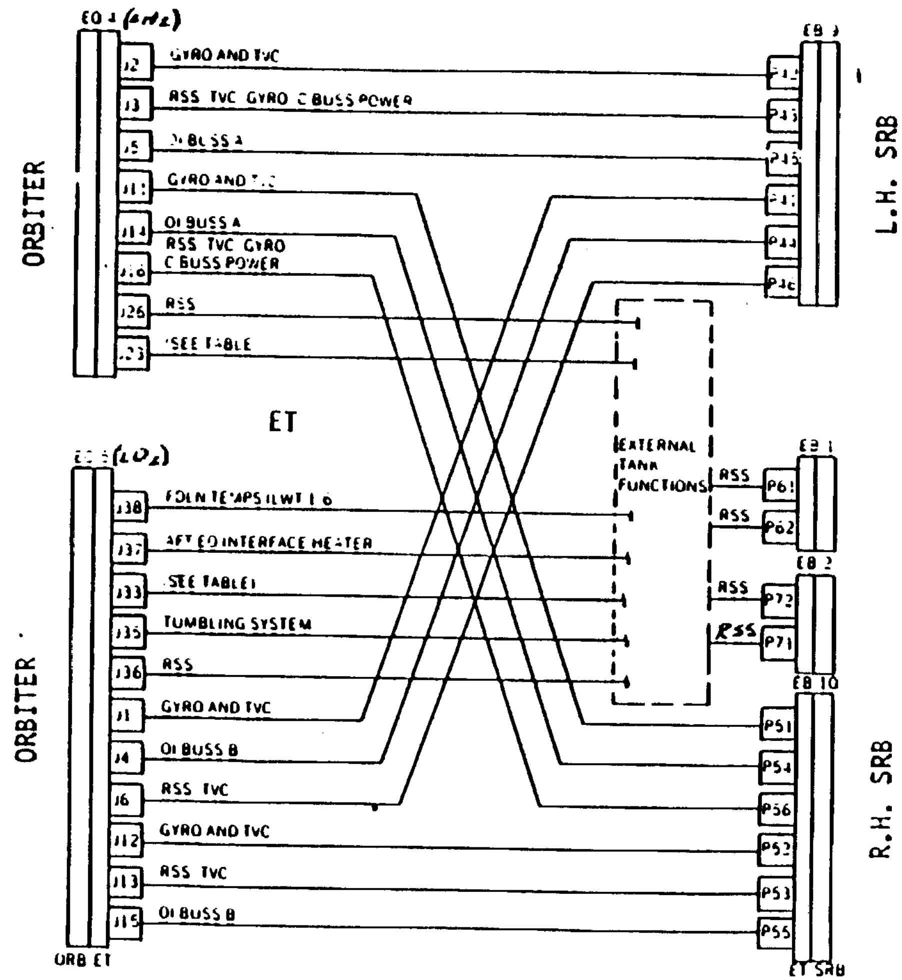
Data bus interfaces provide easier function growth capability than discrete wiring. MDM serial bus restricts options.

MDM	BUS	A/D
8	10	5



LEFT LRB CABLE CONNECTIONS

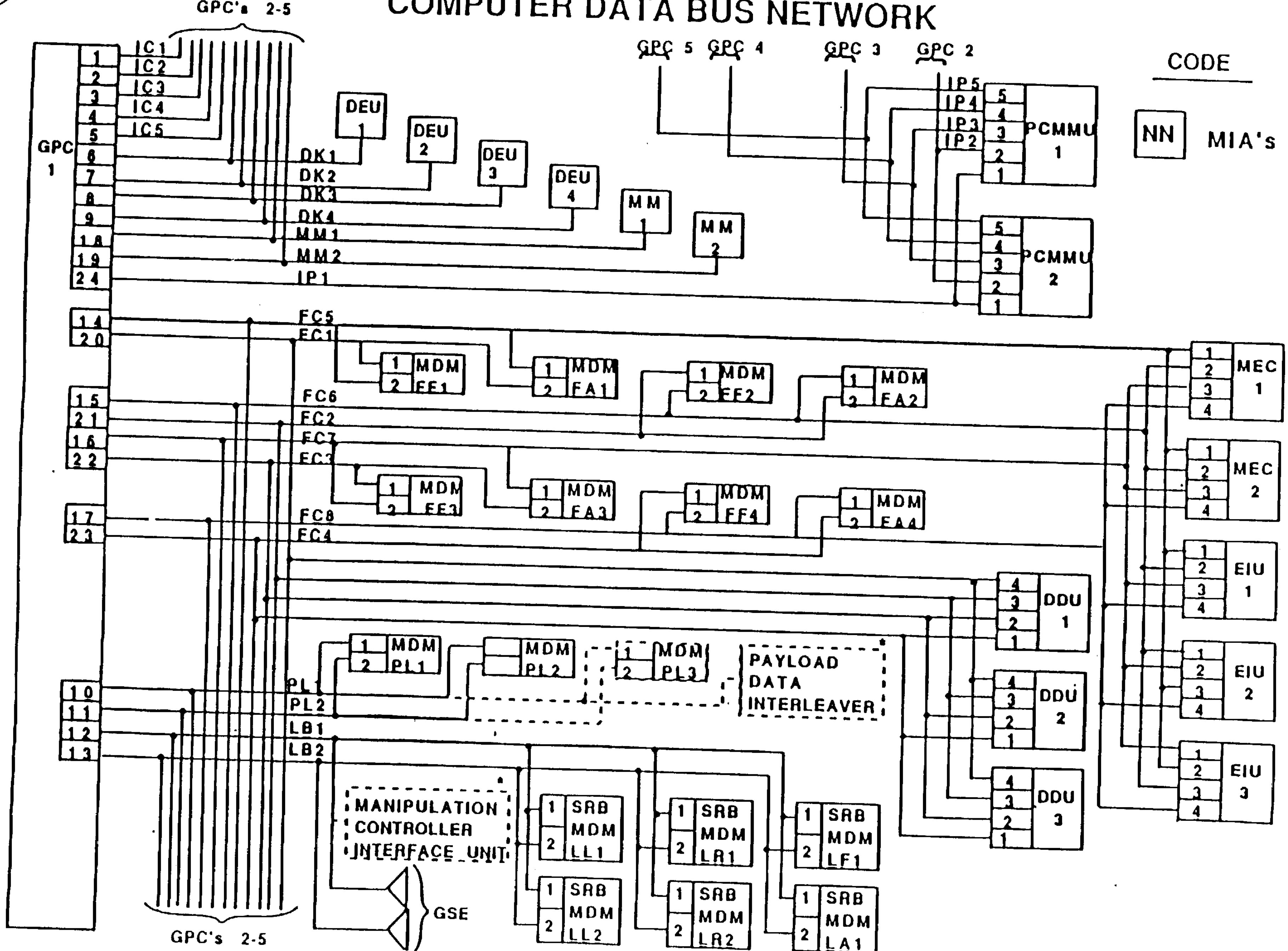
ORBITER/ET/SRB INTERFACES



2Y

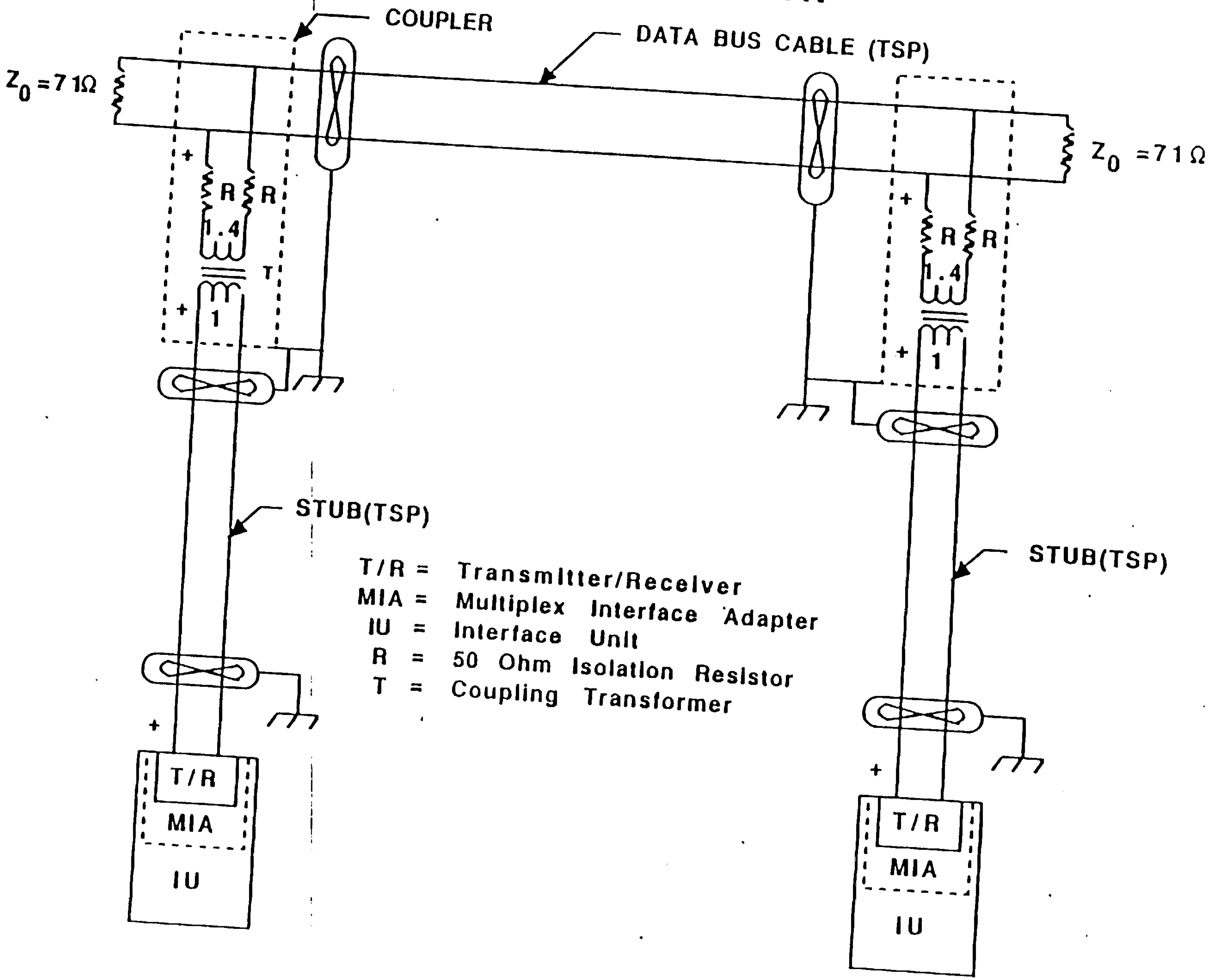
	SRB CONTROL INTERFACE		LRB CONTROL INTERFACE
TVC	ANALOG/DISC (CMD, BYPASS, ΔP)		ANALOG/DISC (SRB) x 4 ENG = 288 wires
	Three Functions	3	
	QUAD REDUNDANT	x 4	
	TILT AND ROCK	x 2	
	3 wires ea	x 3	
	total wires	72	
ENG CONTROL	ANALOG/DISC IGNITION: (ARM, FIRE 1,2, CAP voltage)	7 wires	Serial buses 3 ea x 4 (eng) x 3 wires ea = 36 wires
	A, B	x 2 = 14	
	Chamber Press	3	
	A, B, C	x 3 = 9	
	wires	23	

COMPUTER DATA BUS NETWORK



* PLANNED FOR POST-OF12 FLIGHTS

DATA BUS CONFIGURATION



DIGITAL DATA BUS NETWORK

<u>PROVIDES</u> THE SIGNAL MATCHING, ISOLATION AND FAULT PROTECTION NECESSARY FOR A PARTY LINE DIIGITAL TRANSMISSION SYSTEM

<u>DATA BUS MECHANIZATION</u>

- SERIAL DIGITAL
- 1 MHZ MANCHESTER BI-PHASE LEVEL CODE
- TIME DIVISION MULTIPLEXED
- HALF DUPLEX TIME-SHARED TWO WAY TRAFFIC
- COMMAND AND RESPONSE DATA TRANSPER, MASTER, SLAVE WITH THE GPC IOP MASTER
- SHIELDED TWISTED PAIR
- CAPACITY OF 30,000 28 BIT WORDS (WITH A 5.5 ± 0.5 MICRO SEC INTERWORD GAP) PER SECOND

NOTE: THE MULTICHANNEL DATA BUS NETWORK WAS ESTABLISHED PRIMARILY FOR REDUNDANCY AND ISOLATION OF FUNCTIONS AND EQUIPMENT, NOT TO SATISFY TRAFFIC REQUIREMENTS

<u>TRANSFER METHOD/INTERFACE</u>

- THE GPC IOP COMMUNICATES WITH SUBSYSTEM VIA 24 SEPARATE DATA BUSSES
- INTERFACE IS ACCOMPLISHED BY 24 MULTIPLEX INTERFACE ADAPTERS (MIA's) LOCATED IN EACH GPC IOP

IOM ALLOCATIONS FOR THE SEVEN BASIC TYPES OF ORBITER MDM's

DY01-87.5

I/O Modules (IOM's)	Flight Critical MDM's (GN&C Function)		Mission Critical MDM's(Payload Processing, Performance Monitoring)	Ground Interface (Prelaunch)	Flight Instrumentation		
	4 MDM's FF1-4	4 MDM's FA1-4	2 MDM's PF1-2	2 MDM's LF1 LA1	3 MDM's OF1-3	1 MDM OF-4	3 MDM's OA1-3
Analog input single-ended (range: +5.11 to -5.12 vdc; maximum input: 5.12 vdc)	1	1	2	1	8	3	8
Analog input differential (range: +5.11 to -5.12 vdc; maximum input: 5.12 vdc)	3	2	2	1	1	-	-
Analog output differential (range: +5.11 to -5.12 vdc; maximum output: 5.12 vdc)	1	4	1	1	-	-	-
Discrete input low (+5 vdc)	2	2	3	2	2	3	3
Discrete output low (+5 vdc)	2	3	4	2	-	-	-
Discrete input high (+28 vdc)	2	2	2	3	4	8	5
Discrete output high (+28 vdc)	2	2	1	6	-	-	-
Serial input/output	2	-	1	-	1	-	-
TACAN/radar altimeter	1	-	-	-	-	-	-

3.2.1.4 Serial Digital I/O Channel. The characteristics of serial-digital input/output channels between MDM and the vehicle subsystem shall be half-duplex, Manchester II bi-phase, at a 1-megabit rate.

3.2.1.4.1 Channel Interface. One serial-digital I/O channel shall consist of the following: (See Figure 8.)

a. Data

b. Word discrete output

c. Message out discrete output

d. Message in discrete output

In orbiter operation, some channels, or message lines within a channel, may not be connected to an external subsystem.

3.2.1.4.2 Cable. The cable used to transfer serial-digital data and enable signals shall be a two-conductor twisted, single-shield, jacketed cable equivalent to a twin-axial cable having 71 ohms plus or minus 10-percent impedance with a distributed capacitance no greater than 50 picofarads per foot. There shall be one cable dedicated to the transmission of data words, one cable dedicated to message in enable, one cable dedicated to message out enable, and one cable dedicated to word discrete.

3.2.1.4.3 Input/Output Circuit Characteristics. The message-in discrete, message-out discrete, word discrete (Figure 9) shall be differential (double-ended) monotonically changing discrete outputs. The output circuit shall be capable of driving no less than 150 feet of cable (see paragraph 3.2.1.4.2). The discrete output circuits shall be electrically referenced to the MDM signal ground. Skew between signal outputs of the differential driver shall not exceed 50 nanoseconds. Plus or minus 32 volts applied through 320 ohms to any message or word discrete output line shall neither cause MDM malfunction nor affect MDM operation. This overvoltage shall appear only on one line at a time. The electrical characteristics of discrete output signals shall be as follows:

Signal Parameter	Characteristics
Type	Differential output
Logic Level "one"	Plus 3.0 to 5 volts
Logic Level "zero"	Minus 3.0 to minus 5 volts
Output Impedance - line-to-line or line-to-ground	50 ohms (maximum) over the frequency range of 500 kHz to 3.5 mHz and 100 ohms maximum from dc to 10 kHz
Overshoot and Undershoot	0.25 volts (maximum)

LRB STUDY

CORRELATION MATRIX

SOFTWARE LANGUAGE TRADE STUDY

	HAL-S	ADA	ASSEMBLY	C
STS INTEGRATION IMPACTS	5.5	9.4	5.0	10.0
DDT & E COSTS	4.3	10.0	4.1	9.0
TECHNICAL RISKS	4.6	10.0	5.1	9.6
SAFETY/RELIABILITY	5.4	10.0	6.8	9.6
SUBSYSTEM INTEGRATION	3.0	10.0	6.1	9.4
TEST REQUIREMENTS	4.2	10.0	4.5	9.2

HML29D1

STRUCTURED LANGUAGE: A structured language will affect the following criteria:

- DDT&E Costs: A highly structured software language will result in lower DDT&C costs since it promotes the decomposition of tasks and requirements into modular and finite modules which are easily understood and maintainable. The DDT&E process will proceed in a faster and more organized fashion by utilizing a structured language.

- Technical Risks: Structured software languages reduce technical risk since large and complex tasks are implemented in a more straight-forward and logical manner. Since structured languages implement similar constructs, algorithms and techniques developed for previous applications are easily ported across structured languages.

- Safety/Reliability: Structured software is easier to review and understand. Extensive review and in depth understanding by the entire team will be required to obtain safety and reliability confidence in the application software.

- Test Requirements: Establishing test requirements will involve a clear understanding of the system requirements and how to design tests to demonstrate how the software meets those requirements. Structured software provides a more timely and accurate approach to establishing, conducting, and analyzing test requirements.

RATING

10 ADA is a highly structured language and goes beyond structure to include:
- strong data typing
- packages
- generics
- extensibility

6 HAL-S is a structured language but dated compared to ADA

1 Assembly language can be forced to be structured, but is not intrinsic to the language

9 C is a highly structured language and goes beyond structure to include:

- Strong data typing
- Pointer types

EFFICIENT CODE GENERATION: Memory requirements are directly related to the size of code generated by the compiler. The size of the supporting runtime which is linked to the application software is also a factor. Clearly a software language which supports re-entrancy and recursion will reduce the size of the software load modules. Efficient code generation will affect the following criteria:

- **STS Integration Impacts:** During STS Integration, memory may be a limited resource and changes in scope during STS integration could result in exceeding available memory. An efficient code generator and small run-time package would provide a margin for growth.

- **Technical Risks:** A software language with an efficient code generator with a small efficient runtime will result in fewer "surprises" during DDT&E and IT&V. A smaller software load module requires less memory thus reducing size, weight, and power requirements.

- **Safety/Reliability:** Since a smaller software load module requires less memory, fewer memory components are required which increases safety and reliability of the overall system.

- **Subsystem Integration:** The benefits of small load module for subsystem integration are the same as for STS Integration.

RATING

7 ADA currently is not as code generation efficient as C, Jovial or Pascal. This due to the maturity of ADA and the previous emphasis by vendors to be ADA compliant and certified. Now that vendors are certified, their focus is efficiency for DoD real time, size, weight, and power requirements. The number of users will accelerate the maturity of ADA in a very short period of time. Funding by DoD and NASA will support code efficiency development activities.

5 HAL-S is a general purpose language that has good efficiency. Efficiency improvements, if any, will be small .

8 Assembly is as efficient as the programmer. Large software projects are not performed efficiently in assembly language unless strong design guidelines are enforced.

10 C is very efficient for code generation. C is used extensively for applications where efficient code generation is a requirement.

REAL TIME CAPABILITY: A software language must provide efficient algorithm generation and provide a deterministic scheduler/dispatcher to meet the real time requirements of a controller. The code generator must optimize and avoid extensive looping, indirect addressing modes, and CPU intensive instructions whenever possible. The scheduler/dispatcher must provide for a variety of scheduling/dispatching options and support a deterministic major/minor cycle environment. The real time capability will affect the following criteria:

- **DDT&E Costs:** The robustness of real time features will reduce DDT&E costs because if they are not available, the SE features will have to be developed or alternative approaches developed.

- **Technical Risks:** Lack of real time features will increase technical risks as "kludges" and "workarounds" are implemented.

- **Safety/Reliability:** Development of "kludges" and "workarounds" to compensate for lacking real time features of a software language result in decreased safety and reliability of the system. "Kludges and "workarounds" are intrinsically difficult to verify.

- **Subsystem Integration:** Many real-time issues surface during integration to the subsystem. "Kludges" and "workarounds" add significant time and cost to the subsystem Integration effort since it ripples back to the DDT&E effort, frequently when the DDT&E effort is considered done.

- **Test Requirements:** A software language which provides real time features make test requirements easier to define since real time "kludges" and "workarounds" don't have to be tested.

RATING

7 ADA currently has a poor performance in real time. This is due to vendor emphasis on compliance and certification. Now that vendors are certified, the emphasis for DoD and NASA contracts is for ADA to provide real time capability. Real time capability for ADA is imminent.

5 HAL-S is a general purpose language and has not been used extensively for real-time applications.

10 Assembly language is real time and subject to the designers ability to design real time software. Real time schedulers and dispatchers are readily available.

10 C language has real time support and is utilized extensively for real time applications.

<u>MATURITY</u>: The maturity of a software language assures that previous testing and evaluation has refined the software language. Intrinsically, new software languages have a repertoire of "extensions" to provide features and functionality not originally designed into the software language. Maturity will affect the following criteria:

- **DDT&E Costs:** Mature software languages present fewer "surprises" during the DT&E phases of a project. Planning and scheduling are more accurate with a mature software language since there is usually a history available for estimating. Previous programs have many modules which can be utilized for the current program.

- **Technical Risks:** Technical risk will be lowered by using a mature software language since there is a performance record and experience base with mature software languages.

- **Safety/Reliability:** Since there are fewer "surprises" with a mature software language, safety and reliability would be increased.

- **Subsystem Integration:** Mature software languages generally have hardware and software support tools which have been developed for the integration effort.

- **Test Requirements:** Test requirements are more easily defined and tested when there are hardware and software integration support tools available with a knowledge base and track record.

<u>RATING</u>

6	ADA is not mandates currently mature, but with the strong investment by vendors, the mandates of NASA and DoD, and subsystem contractor investment, ADA will mature faster than any previous software language. ADA is the first language to have a validation sweet so that maturity is less of a risk.
8	HAL-S is mature but has few applications beyond Shuttle.
10	Assembly language is mature.
10	C is a mature language with many applications developed for commercial and DoD applications.

COMMONALITY: Commonality in hardware and software has become a driving force and a primary requirement for future space programs. A common set of software development, testing and integration tools is the emphasis of the SSE. GFE equipment, a large vendor user base, and NASA sponsorship will provide a broad capability for software development. Commonality will affect the following criteria.

- DDT&E Costs: GFE equipment and a large vendor user base will provide additional DDT&E cost benefits beyond the obvious benefit of common and re-useable elements in software.

- Technical Risk: Commonality will greatly reduce technical risk since a widely distributed knowledge base will be available for common elements.

- Safety/Reliability: Commonality will enhance safety and reliability due to re-useable elements that have been previously tested and verified.

- Subsystem Integration: Commonality will provide a complete set of support equipment for subsystem integration which should improve cost and schedule for subsystem integration.

- Test Requirements: Since commonality will provide a well-defined and documented set of hardware and software support equipment, test requirements should benefit by the available equipment and documentation.

RATING

10 ADA is designed for commonality. The available packages for ADA will grow at an exponential rate.

1 HAL-S is common to HAL-S and will have no legacy into future space programs.

1 Assembly language will have no legacy into future space programs.

1 C is not specified for implementation into Space Station.

GROWTH: Growth can occur throughout a program as well as once a program is completed through changes in requirements and scope. These changes can affect every phase of a program and often do. The growth capability of a software language centers around how well the software is structured, documented and implemented. Growth capability of a software language will affect the following criteria:

- **STS Integration Impacts:** Changes in scope and requirements during STS integration will be implemented faster with a software language that accommodates growth.

- **DDT&E Costs:** Evolving requirements during the DDT&E phase are more easily integrated by a software language that accommodates growth which results in lower cost.

- **Technical Risks:** A software language which accommodates growth provides lower technical risks for all phases of a program.

- **Safety/Reliability:** A software language which accommodates growth results in fewer overall changes for a given change in scope or requirements thus increasing safety and reliability.

- **Subsystem Integration:** Any growth changes which occur during subsystem integration can be implemented quicker by a software language which accommodates growth resulting in a shorter subsystem integration phase.

RATING

10 ADA is designed to accommodate growth more than any other software language because ADA is independent of architecture and operating system environments.

5 HAL-S is a structured language and can accommodate growth.

1 Assembly language applications are tightly coupled and generally not designed for growth.

8 C language is designed to accommodate growth.

FLEXIBILITY: A flexible software language provides for loose coupling between software modules and a system environment which allows portability of modules. A flexible software language will affect the following criteria:

- DDT&E Costs: Flexibility is a key feature during the DDT&E phase when design options are being traded-off and changes are affecting design. A flexible software language can significantly shorten the DDT&E phase and significantly lower cost.
- Technical Risks: Flexibility can reduce technical risk when a variety of design options are available.
- Test Requirements: Flexibility allows for test software to be inserted and removed easily. In vivo testing becomes easier and test requirements can benefit by working within the software environment as well as outside the software environment.

RATING

10	ADA is highly flexible by design.
5	HAL-S because it is structured, is viewed to be flexible.
1	Assembly language applications are intrinsically not flexible.
10	C is highly flexible by design and has bred success in porting across architectures and systems.

<u>COMPUTER TEST EQUIPMENT</u>: Micro and mini computers are beneficial as test consoles for software development and integration. A software language that would also target into commercial micro and mini computers would provide a more efficient DDT&E and IT&V environment, through reduced training, overall configuration control and better utilization of human resources. A software language which could be targeted for computer test equipment would affect the following criteria:

- DDT&E Costs: Software personnel could be better utilized and development time reduced for computer test equipment if the candidate software language could be utilized in the computer test equipment and the application.

- Subsystem Integration: Computer test equipment is heavily utilized during the subsystem integration phase. A homogeneous software development environment for application and computer test equipment software would reduce the interface complexity between the development engineers and test engineers.

<u>RATING</u>

10	ADA is available for micro and mini computers as well as mainframes.
1	HAL-S is only available for STS GPC computers.
5	Assembly language is available for any computer, but very laborious to implement for test equipment.
10	C is available for micro and mini computers as well as mainframes.

<u>DOCUMENTATION TOOLS</u>: A software language which offers an integrated set of documentation tools such as PDL (Program Description Language) processor helps to tie the requirements definition and verification process to the DT&E and IT&V processes. Document outlines from the requirements documents can be used as templates for the application and test software development process. Management also benefits from documentation tools which are integrated with the development tools. Error reporting and problem tracking are more automated with documentation tools. Documentation tools will affect the following criteria:

- **DDT&E Costs:** The process of turning requirements into design is aided by documentation tools. The process of assuring that the design is meeting the requirements is made more obvious by the use of documentation tools.

- **Subsystem Integration:** The process of subsystem integration is aided by documentation tools since documents are more standardized and information is easier to find.

- **Test Requirements:** The definition of test requirements can proceed along with the DDT&E process easier since documentation is automated.

<u>RATING</u>

10 ADA vendors are supplying every documentation tool envisioned to maintain a competitive edge.

2 HAL-S has documentation tools but they will not keep pace with ADA.

1 Assembly language does not intrinsically provide documentation tools.

8 C has many documentation tools but these tools will keep pace or be compatible with these.

SOFTWARE DEVELOPMENT TOOLS: Software development tools are both hardware and software. Real-time support systems, in circuit emmulators, symbolic debuggers, language sensitive editors, etc. are all tightly coupled with a software language and in most cases, the vendor supplying the software language. Software development tools will affect the following criteria:

- **DDT&E Costs:** Software development tools are essential during the DDT&E process. The quality and fidelity of the tools will have direct impact on the DDT&E process.

- **Technical Risks:** Software development tools can lower technical risk because they provide the ability to detect and identify technical problems in the hardware and software early in the test and evaluation phase and later in the integration phase.

- **Subsystem Integration:** The integration of real time software with subsystems is greatly aided by software development tools. Test equipment alone is often not enough to perform the subsystem integration process.

- **Test Requirements:** The capabilities of software development tools during the IT&V phase aids in the generation of test requirements.

RATING

10 ADA has a very complete set of software development tools and these tools will continue to be state of the art with DoD and NASA support.

3 HAL-S will not keep pace with ADA in the area of software development tools.

4 Assembly language inherently must have a minimum set of software development tools.

9 C has a very complete set of software development tools.

LRB STUDY

CORRELATION MATRIX RATING HAL-S

		STRUCTURED LANGUAGE	EFFICIENT CODE GENERATION	REAL TIME CAPABILITY	MATURITY	COMMONALITY	GROWTH	FLEXIBILITY	COMPUTER TEST EQUIPMENT	DOCUMENT TOOLS	SOFTWARE DEVELOPMENT TOOLS
STS INTEGRATION IMPACTS	10		5				5				
DDT & E COSTS	36	6		5	8	1	5	5	1	2	3
TECHNICAL RISKS	32	6	5	5	8	1	5	5			3
SAFETY/RELIABILITY	27	6	5	5	8	1	5				
SUBSYSTEM INTEGRATION	21		5	5	8	1	5		1	2	3
TEST REQUIREMENTS	31	6		5	8	1		5	1	2	3

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LRB STUDY

CORRELATION MATRIX RATING ADA

		STRUCTURED LANGUAGE	EFFICIENT CODE GENERATION	REAL TIME CAPABILITY	MATURITY	COMMONALITY	GROWTH	FLEXIBILITY	COMPUTER TEST EQUIPMENT	DOCUMENT TOOLS	SOFTWARE DEVELOPMENT TOOLS
STS INTEGRATION IMPACTS	17		7				10				
DDT & E COSTS	83	10		7	6	10	10	10	10	10	10
TECHNICAL RISKS	70	10	7	7	6	10	10	10			10
SAFETY/RELIABILITY	50	10	7	7	6	10	10				
SUBSYSTEM INTEGRATION	70		7	7	6	10	10		10	10	10
TEST REQUIREMENTS	73	10		7	6	10		10	10	10	10

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LRB STUDY

CORRELATION MATRIX RATING ASSEMBLY

		STRUCTURED LANGUAGE	EFFICIENT CODE GENERATION	REAL TIME CAPABILITY	MATURITY	COMMONALITY	GROWTH	FLEXIBILITY	COMPUTER TEST EQUIPMENT	DOCUMENT TOOLS	SOFTWARE DEVELOPMENT TOOLS
STS INTEGRATION IMPACTS	9		8				1				
DDT & E COSTS	34	1		10	10	1	1	1	5	1	4
TECHNICAL RISKS	36	1	8	10	10	1	1	1			4
SAFETY/RELIABILITY	34	1	8	10	10	1	1				
SUBSYSTEM INTEGRATION	43		8	10	10	1	1		5	1	4
TEST REQUIREMENTS	33	1		10	10	1			5	1	4

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LRB STUDY

CORRELATION MATRIX RATING C

		STRUCTURED LANGUAGE	EFFICIENT CODE GENERATION	REAL TIME CAPABILITY	MATURITY	COMMONALITY	GROWTH	FLEXIBILITY	COMPUTER TEST EQUIPMENT	DOCUMENT TOOLS	SOFTWARE DEVELOPMENT TOOLS
STS INTEGRATION IMPACTS	18		10				8				
DDT & E COSTS	75	9		10	10	1	8	10	8	9	10
TECHNICAL RISKS	67	9	10	10	10	1	8	10		9	10
SAFETY/RELIABILITY	48	9	10	10	10	1	8				
SUBSYSTEM INTEGRATION	66		10	10	10	1	8		8	9	10
TEST REQUIREMENTS	67	9		10	10	1		10	8	9	10

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